Report Title: Certificate in Training in Low Energy Buildings
Module 2 – Building Fabric
Module Learner Manual

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Further information

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# Table of Contents

**List of Abbreviations** ........................................................................................................... 1

**Definitions** .......................................................................................................................... 2

**Module Description** ............................................................................................................. 4

**Unit 1: Heat Loss in Buildings** ........................................................................................... 10

1. **Unit 1 Section 1 Modes of Heat Transfer** ..................................................................... 11
   1.1 Introduction ...................................................................................................................... 12
   1.2 Laws of Thermodynamics ................................................................................................. 13
   1.3 Modes of Heat Transfer ..................................................................................................... 18
   1.4 Heat Transfer in Buildings ............................................................................................... 23
   1.5 Heat Gain in Buildings ...................................................................................................... 29

2. **Unit 1 Section 2 Air Permeability and Thermal Bridging** .............................................. 41
   2.1 Introduction ...................................................................................................................... 42
   2.2 Ventilation versus Air Infiltration .................................................................................... 43
   2.3 Air Tight Construction ..................................................................................................... 48
   2.4 Thermal Bridging .............................................................................................................. 53
   2.5 Principle of continuity of the thermal envelope in a building ............................................ 68

**Unit 2: Measuring Building Fabric Performance** ................................................................. 78

1. **Unit 2 Section 1 Heat Loss Calculation** ....................................................................... 79
   1.1 Introduction ...................................................................................................................... 80
   1.2 Measuring Heat Loss ......................................................................................................... 81
   1.3 Calculating U-Values ....................................................................................................... 90
   1.4 Building Element U-Values for Walls ............................................................................ 96
   1.5 Building Element U-Values for Floors .......................................................................... 105
   1.6 Building Element U-Values for Roofs ......................................................................... 110
   1.7 Building Element U-Values for Windows & Doors ....................................................... 115
List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEH</td>
<td>Better Energy Homes</td>
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<tr>
<td>BER</td>
<td>Building Energy Rating</td>
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<td>BEWH</td>
<td>Better Energy Warmer Homes</td>
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<tr>
<td>DCENR</td>
<td>Department of Communications, Energy and Natural Resources</td>
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<td>DEAP</td>
<td>Dwelling Energy Assessment Procedure</td>
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<tr>
<td>DECLG</td>
<td>Department of the Environment, Community and Local Government</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Efficiency</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
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<td>GHS</td>
<td>Greener Homes Scheme</td>
</tr>
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<td>GWh</td>
<td>Gigawatt Hour</td>
</tr>
<tr>
<td>HES</td>
<td>Home Energy Saving scheme</td>
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<tr>
<td>kWh</td>
<td>Kilowatt Hour</td>
</tr>
<tr>
<td>MPEPC</td>
<td>Maximum Permitted Energy Performance Coefficient</td>
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<tr>
<td>MPCPC</td>
<td>Maximum Permitted Carbon Performance Coefficient</td>
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<tr>
<td>MVHR</td>
<td>Mechanical Ventilation with Heat Recovery</td>
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<tr>
<td>NEAP</td>
<td>Non-domestic Energy Assessment Procedure</td>
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<tr>
<td>NEEAP</td>
<td>National Energy Efficiency Action Plan</td>
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<tr>
<td>NERP</td>
<td>National Energy Retrofit Programme</td>
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<tr>
<td>NREAP</td>
<td>The National Renewable Energy Action Plan</td>
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<td>NSAI</td>
<td>National Standards Authority of Ireland</td>
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<td>QQI</td>
<td>Quality and Qualifications Ireland</td>
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<td>SEAI</td>
<td>Sustainable Energy Authority Ireland</td>
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<td>SME</td>
<td>Small and Medium Enterprise</td>
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<tr>
<td>SSC</td>
<td>Sector Skills Councils</td>
</tr>
<tr>
<td>TGD</td>
<td>Technical Guidance Documents</td>
</tr>
<tr>
<td>WHS</td>
<td>Warmer Homes Scheme</td>
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**Air Infiltration:** Air infiltration is the uncontrolled entry of fresh air into a building through air leakage paths, e.g. gaps at junctions between external building elements and around openings, unsealed penetrations of the building envelope accommodating services.

**Building Envelope:** The building envelope is the line of separation between the inside and outside environments of a building.

**Building Physics:** Building Physics refers to Applied Science dealing with the hygrothermal (the movement of heat and moisture through buildings), acoustical and light related properties of building components (roofs, facades, windows, partition walls etc.), rooms, buildings and building assemblies. Basic considerations include requirements for thermal, acoustic and visual comfort, healthy environment within limitations imposed by architectural, material-related, economic and ecological considerations [Building Physics – Heat, Air and Moisture, Hugo Hens, 2007, Ernst and Sohn]

**Deep Retrofit:** We define deep retrofit as an investment in energy efficiency which saves the homeowner 40% or more on energy bills. A deep retrofit investment will generally involve a combination of roof and wall insulation, a new renewable or highly efficient heating system, and heating controls. [Thinking Deeper – Financing Options for Home Retrofit, Joseph Curtin & Josephine McGuire, 2011]

**Energy consumption:** The amount of energy consumed in the form in which it is acquired by the user. The term excludes electrical generation and distribution losses.

**Energy performance of a building:** the amount of energy actually consumed or estimated to meet the different needs associated with a standardised use of the building, which may include, inter alia, heating, hot water heating, cooling, ventilation and lighting. This amount shall be reflected in one or more numeric indicators which have been calculated, taking into account insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighbouring structures, own-energy generation and other factors, including indoor climate, that influence the energy demand [EPBD, 2002/91/EC]
**Nearly zero energy building:** a building that has very high energy performance, as determined in accordance with Annex I of the EPBD recast. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby [EPBD recast, 2010/31/EC]

**Primary energy:** Energy from renewable and non-renewable sources which has not undergone any conversion or transformation process.

**Public building:** building owned or occupied by any public body.

**Residential building:** A structure used primarily as a dwelling for one or more households. Residential buildings include single-family houses (detached houses, semi-detached houses, terraced houses (or alternatively row houses) and multi-family houses (or apartment blocks) which includes apartments/flats.

**Thermal Bridging:** Fundamental of heat transfer that occurs in building envelopes when materials with high thermal conductivity (also called non-insulating material), such as steel, timber and concrete create pathways for heat loss that bypass thermal insulation.

**Thermal Conductivity:** the property of a material to conduct heat.

**U-Value:** U-value is the measure of the rate of heat loss through a material. It represents the amount of heat lost through one square meter of the material for every degree difference in temperature either side of the material. It is indicated in units of Watts per meter squared per degree Kelvin or W/m²K.

**Ventilation:** Ventilation is the controlled supply of outside fresh air to a building by natural and/or mechanical systems.
In Ireland, buildings account for more than 31% of the total energy consumed along with the resultant CO₂ emissions¹. International climate change agreements have focused on this and have been the one of the main driving forces responsible for the evolution of building energy efficiency standards in Ireland over the past 2 decades. To achieve energy saving targets for 2020, the minimum threshold levels for compliance with Part L of the building regulations have increased to a level which necessitates a new holistic approach to building construction. Revisions to the building regulations have focused on reducing the demand for energy through passive measures while simultaneously increasing the supply of energy from renewable/cleaner sources. The “fabric first” approach to building, which is based on the principles of a continuous thermal and air tight envelope in the building fabric, dramatically reduces the demand for energy thus contributing to reduced overall CO₂ emissions.

Maintaining a continuous thermal and air-tight envelope is integral to the energy performance of the building and as a result is totally dependent on the specification, quality of installation and attention to detail for every aspect of the fabric. To achieve and maintain the high performance of the building, all building workers will need to understand the basic underlying principles and be aware of the consequences of any actions or omissions during the construction process.

The introduction of air permeability standards and guidelines for counteracting the effect of thermal bridging fundamentally affect the approach to onsite practices. Building high performance fabric requires a rigid attention to detail and specification to achieve. However, this new approach must account for the provision or maintenance of adequate ventilation levels in a building. The consequences of poor detailing include compromised air quality and decay of the building fabric.

This module is the second in a 4-module programme (see Figure 0.1) designed to up-skill trainers of construction trades to deliver foundation energy skills training and to prepare them for anticipated revisions to apprenticeship curricula in the future.

¹ SEAI, (2013), Energy in Ireland 1990 - 2012
The module sets the context for the need for change in approach that will be required onsite to deliver low energy buildings and also details the current drivers for implementation of energy efficient technologies in buildings.

For you as a trainer of building construction workers, it is important that you are aware of factors that affect the thermal performance of the building fabric.

**Module Aims**

This module aims to provide you with knowledge of:

- the underpinning principles of building fabric technology in low energy buildings
- the methods by which building fabric performance is measured in the Irish building regulations
- the properties of insulation materials and details of insulation systems that are commonly used to achieve low energy buildings
Module Overview

The module is divided into three units and each unit is sub-divided into two sections as outlined in Figure 0.2 below.

**Figure 0.2: Module Structure**

**Unit 1: Heat Loss in Buildings**

**Section 1 (Modes of Heat Transfer):** In this section you will learn about the heat transfer mechanisms that occur in building fabric and how they contribute to heat transfer, i.e., heat loss and/or heat gain.

**Section 2 (Air Permeability and Thermal Bridging):** This section explains the difference between ventilation and air infiltration and how air leakage can affect energy performance.

**Unit 2: Measuring Building Fabric Performance**

**Section 1 (Heat Loss Calculation):** Covers the methods used in the Building Regulations for calculating the performance of external building fabric.

**Section 2 (Measuring Performance with DEAP):** Provides an overview of the Dwelling Energy Assessment Procedure (DEAP) sections on ventilation and building elements and the inputs required for calculating whole building heat loss.
Unit 3: Insulation Material and Systems

Section 1 (Properties of Insulation Materials): This section considers the properties of insulation materials commonly used in the construction and renovation of buildings.

Section 2 (Common Insulation Systems): This section provides an overview of insulation systems used in low energy building for floors, walls and roofs.

Module Learning Outcomes

On successful completion of this module you will be able to:

1. List and describe the modes of heat transfer, laws of thermodynamics and factors that contribute to heat loss and gains in buildings
2. Outline the principles of air tight construction and identify common air leakage pathways in buildings.
3. Explain the impact of thermal bridging on energy performance in buildings, and illustrate good practice examples of detailing to mitigate its effect.
4. Outline the methods for calculating the energy performance of the external fabric of a dwelling as described in the current Building Regulations
5. Compare the properties of commonly used building insulation materials/systems and relate to the criteria to be considered in determining their suitability for selection
6. Describe the relationship between ventilation, vapour control, thermal mass and surface /interstitial condensation in building fabric

Tips for Using the Module Manual

You are expected to read the manual prior to attending the scheduled workshop. This is necessary to provide you with the best opportunity for learning at both workshops and associated site visits. Module assignments and activities will be based on the content of the manual. The following approach is recommended:

- Work through the module material sequentially, as the order is important in understanding of contents.
- Complete the module Activities and Progress Checks as you proceed
- Take note of the summary, key points and additional reading references, they are designed to help you retain important information
• A list of definitions is provided at the beginning of the manual for reference as you work through the Units and Sections in the manual
• If something is unclear to you or you require clarification take note of it, you will have an opportunity to discuss with your tutor at workshops and site visits.

Legend for Icons

The following icons are used to highlight sections of the module:

**Learning outcomes**
At the beginning of each unit and section

**Key learning point**
Highlighting main points in text

**Activity**
Where you are asked to complete an exercise to explore a topic further

**Progress Check**
At the end of each section to allow you to assess your own progress

**Summary**
At the end of each section summing up the main points

**Further Reading**
At the end of some sections you will be provided with suggestions for further reading
Unit 1: Heat Loss in Buildings

Heat loss in buildings can occur through the fabric of the building and also through air movement/ventilation. It is essential to maintain air quality within a building by providing a sufficient number of air changes each hour. However, uncontrolled air leakage will have a profound impact on the rate of heat loss as well as contribute to draughts, cold spots and damp areas within the building.

Maintaining an ambient comfortable temperature within the living space is challenging and potentially costly. Materials used in the construction of the fabric of the building need to be capable of resisting the passage of heat and uncontrolled air movement. In previous years, insufficient emphasis on designing energy efficient buildings has contributed to a high cost of energy for heating. To reduce this energy consumption and associated CO₂ emissions, consideration must be given to materials and construction details during the design and build stages.

This Unit considers the ways in which heat is lost and gained in buildings affecting the energy performance, from the modes of heat transfer to the effect of bypass in the building envelope. This includes an examination of the impacts of thermal bridging and air leakage on energy consumption, comfort levels of occupants, indoor air quality and building life cycle.

After completing this unit, you will be able to:

1. List and describe the modes of heat transfer, laws of thermodynamics and control of heat loss and gains in buildings
2. Outline the principles of air tight construction and identify common air leakage pathways in buildings.
3. Explain the impact of thermal bridging on energy performance in buildings and illustrate good practice examples of detailing to mitigate its effect
4. Describe the relationship between ventilation, vapour control, thermal mass and surface /interstitial condensation in building fabric
Unit 1 Section 1

Modes of Heat Transfer
1.1 Introduction

The key function of a building is to provide a comfortable secure space within which to live and work. The level of “thermal comfort” experienced is influenced by factors that affect heat gain and heat loss which include factors such as the air temperature, levels of insulation and the air quality within the space. These factors form part of the construction/renovation process, as such, and are directly related to the knowledge and skills required of all construction workers.

To experience thermal comfort within a space, the environment needs to be such that we can give off excess heat to our surroundings while still maintaining a comfortable body temperature. If our environment does not allow this, we can become uncomfortably hot or alternatively, uncomfortably cold.

Heat transfer is the process by which the energy from one substance transfers to another substance due to differences in temperature. This section explores the different modes of heat transfer and introduces the laws upon which such transfer is guided - the laws of thermodynamics.

**Part L - the requirement**

L1: “A building shall be designed and constructed so as to ensure that the energy performance of the building is such as to limit the amount of energy required for the operation of the building and the amount of carbon dioxide (CO₂) emissions associated with this energy use insofar as is reasonably practicable.”

At the end of this section you will be able to:

1. Describe the Laws of Thermodynamics that govern how heat energy is transferred between systems
2. List and describe the modes of heat transfer that occur in external building fabric
3. Explain the main causes of heat gain in buildings and how to mitigate against possible overheating
1.2 Laws of Thermodynamics

Thermodynamics is the study of energy transfer and its resultant effects. The term “thermodynamics” comes from the Greek “Therme” (Heat) “Dynamis” (Power). While there is only one “energy” it is convenient to consider it in the form of heat, light, chemical, mechanical, solar, electrical or nuclear energy.

We buy energy, sell energy, eat energy, waste energy, fight over energy and talk a little about conserving energy but simply put, energy is the ability to bring about change or to do work.

Heat is a form of energy (thermal energy) that transfers between particles in a system by particles bouncing into each other. Heat is defined as energy in the process of being transferred from one object to another because of the temperature difference between them. It is denoted using the SI unit Joule (J) but it is also commonly measured using Calorie (cal) or British thermal units (Btu).

There are 4 laws of thermodynamics governing how energy can be transferred between systems. The following section details the first three which are most relevant to heat transfer in buildings.

The 0th (zeroth) Law of Thermodynamics

If two thermodynamic systems are each in equilibrium with a third system, then they are in thermal equilibrium with each other

The Zero\textsuperscript{th} law only came about following the 1\textsuperscript{st}, 2\textsuperscript{nd}, and 3\textsuperscript{rd} laws, but was deemed to be most fundamental and as a result is listed first. An example of this law would be if two bottles of beer are kept in a bucket of ice water. They will eventually reach the same temperature as the ice water and also have the same temperature as each other - “thermal equilibrium”. At this point no heat will flow between the water and the bottles of beer or between the two bottles of beer.
The 1st Law of Thermodynamics

Energy can neither be created nor destroyed. It can only change forms

The first law of thermodynamics is an expression of the principle of the Law of Conservation of Energy. In any process, the total energy remains the same it can only be redistributed or changed from one form to another. For any thermodynamic cycle the net heat supplied to the system equals the net work done by the system.

Energy can be stored, moved or transformed into another type of energy but in all this moving and transforming, the total amount of energy never changes – see Figure 1.1.

The energy of a system will change only when heat or work is added or removed.

Figure 1.1: Energy Transformation (Source SEAI)

The human body is a good example of such a system. In order to move (do work) and maintain the body temperature (produce heat) a person must acquire chemical energy in the form of food. No energy ultimately means no heat or work out.

Portable generators are a good example of how the energy generated in a system changes (Figure 1.2). When all of the fuel's energy is released by burning in the
Every time energy changes, it moves to a condition in which some of it or all of it becomes less useful. This is the result of it becoming less concentrated.

A traditional incandescent electric light bulb is an example of how energy can be used inefficiently in buildings. With an incandescent bulb, approximately 10% of the electrical energy is changed to generate light. The remaining 90% of electrical energy changes to generate heat. However, the primary function of the bulb is to provide light.
The Second Law of Thermodynamics is a general principle which places constraints upon the direction of heat transfer. Heat energy can move from areas of higher temperature to areas of lower temperature spontaneously. Energy always, and only, goes from more concentrated to less concentrated, e.g. hot to cold (Figure 1.3). Being less concentrated also means less useful. Consider a building, in winter-time it is warm inside and colder outside so this movement from hot to cold is generally constant during the heating months (October to May in DEAP).

Figure 1.3: Graphical illustration of the 2nd Law of Thermodynamics

Concentrated electrical energy is driven through high voltage cables to your home. Along the way, some of the concentrated energy "leaks" into the air around the power lines, becoming low-grade thermal energy which we cannot reuse and is gone forever.

When the remaining electrical energy reaches our homes, we each take a small portion and convert it to mechanical, thermal or light energy. All of the energy is eventually converted to low-grade thermal energy when the “work” has been accounted for.

The final destination of all the energy from our power plants is thousands of light bulbs, heaters, toasters, washing machines, dryers, stereos, televisions, and other electrical devices in which it is always and finally converted to low-grade thermal energy.
energy that heats up the air around us a little bit. All that formerly concentrated energy is much less concentrated now, all spread out and eventually it radiates out into cold space as electromagnetic radiation.

The Second Law describes how energy eventually and always "runs down" until it can't be re-used for anything except warming the environment around us. It means, in the big picture, that the world of living things powered by the sun, would quickly run down to a cold condition of "not-living", if we didn't get a fresh dose of concentrated solar energy every day.

And what about non-renewable fuels like coal, petroleum, and natural gas? Once the potential chemical energy that is stored within the material is converted to mechanical and thermal energy, it is lost, never to be re-used - forever.

While the Celsius and Fahrenheit scales are the most widely used temperature scales, there are several other scales that have been used throughout history namely the "Kelvin" temperature scale (Figure 1.4). This is the standard metric unit for the measurement of temperature. There are 100 equal degree increments between the normal freezing point and the normal boiling point of water on the Kelvin temperature scale, however, the zero-degree mark on the Kelvin temperature scale is 273.15 units cooler than it is on the Celsius scale. The zero point on the Kelvin scale is known as absolute zero. It is the lowest temperature that can be achieved.

![Figure 1.4: The Kelvin, Celsius and Fahrenheit Temperature Scales](image-url)
1.3 Modes of Heat Transfer

Heat is a form of energy - thermal energy and is constantly flowing into and out of all objects. All matter is made up of molecules and atoms and these atoms are always in different types of motion. The motion of atoms and molecules creates heat or thermal energy and all matter has this thermal energy. The more motion the atoms or molecules have the more heat or thermal energy they will have. Heat flow moves energy from one object to another and is governed by the laws of thermodynamics.

Heat transfer occurs from areas/objects of higher temperature to areas/objects of lower temperature (2nd Law) and the greater the temperature difference between the two areas/objects, the faster heat flows between them. Heat transfer will continue until both areas are of equal temperature and when this state is achieved, there is no change in energy due to heat flow. (0th Law)

There are three factors governed by the Laws that are most relevant to heat transfer in buildings:

1. There has to be a temperature difference. Energy only flows as heat if there is a temperature difference.
2. Energy as heat flows from a higher temperature to a lower temperature.
3. The greater the difference in temperature, the faster the energy flows.

Consider the factors above in relation to a cup of hot liquid sitting on a counter. The cup will only cool down if the air surrounding the cup is cooler than the liquid. The energy doesn't disappear. It flows into the air around the cup and to the counter-top it is sitting on. It also travels into the cooler surfaces within the room – As the cup cools down, the air in the room is heated up.

Similarly, during the heating months, heat in a building flows out into the cooler external environment. The building then cools down requiring further heat energy generation to maintain desired internal temperature. The performance of the external fabric of the building is what dictates the rate of this heat loss.

Heat transfer occurs through 3 different mechanisms and in some situations can involve one, two and sometimes all three mechanisms.

- Conduction
- Convection
- Radiation
Conduction

Conduction is the transfer of energy by the movement of particles that are in direct contact with each other, as either a solid or liquid. Not all materials conduct heat at the same rate and so materials which provide good conduction are called conductors while materials that provide poor conduction are called insulators.

Heat transfer by conduction is a continuous loss of temperature in the direction of the heat flow (hot to cold) through a still solid material.

Conduction can be easily demonstrated by holding a steel rod over a flame (poker in the fire). As metals are generally good conductors, when the end of the steel rod is heated, the heat gradually travels up along the length of the rod through direct molecular contact within the rod until it becomes too hot to hold. Water, on the other hand, is a poor conductor of heat. With the experiment illustrated in Figure 1.5, the water at the top of the test tube will boil without the ice melting.

![Figure 1.5: Conduction (source: SEAI)]

Different materials defer in their conductive properties, hence, are designated a number that indicates their relative rates of conduction. Water, for example is a poor conductor of heat. Thermal conductivity is expressed as the quantity of heat that passes through a unit cube of the substance in a given unit of time when the difference in temperature of the two faces is 1°C or 1K (one degree Kelvin). Thermal conductivity is expressed as the K-value or, more commonly in building construction, the λ.

2 http://www.seai.ie/Schools/Post_Primary/Subjects/Physics/Unit_6_-_Heat_Transfer/Conduction/
(Lambda) value. Thermal conductivity is measured in watts per meter Kelvin (W/mK) or watts per meter degree Celsius. (W/m°C)

To control heat transfer through the building structure, the use of materials with low thermal conductivity in the construction of the fabric is desirable. The low thermal conductivity value attributed to air helps to explain why trapped air is used as the basic premise for so many fabric insulating materials. This factor is explored in more detail in Unit 3 of this module.

**Convection**

Convection is the main method of heat transfer in fluids (liquids and gasses). Unlike conduction, convection involves the actual movement of hot fluids (in this case air), which carries the internal energy with it from an object or place at a higher temperature to one at a lower temperature.

As the actual molecules move during convection, which carries the heat energy with them as a result, the heat transfer can occur over greater distances as it doesn’t rely on direct molecular contact.

**Convection is the energy transfer from warmer locations to cooler locations by the actual movement of the heated liquid or gas (including air)**

Convection in a liquid can be demonstrated by examining how water is heated in a kettle or a holding vessel such as a cooking vessel - see Figure 1.6. The element, located at the bottom of the kettle is heated, and in turn heats up the water at the bottom of the kettle first. Since fluids expand when heated becoming less dense, the heated water rises to the top of the kettle displacing the cooler more dense water which drops to the bottom. This process continues providing the pathway for heated water to transfer energy from the bottom of the kettle through the water in the kettle. The continual cycling of the fluid is called convection or circulation currents and will occur naturally.
Figure 1.6: Illustration of heat transfer by convection in a cooking vessel (source: SEAI)

The same convection currents can be demonstrated in gases (air) by examining how an electric heater located on the floor of a cold room warms up the air in the room. The air in the vicinity of the heating coils warm up and expands, becomes less dense and begins to rise. As the hot air rises, it pushes some of the cold air near the top of the room out of the way. The cold air moves towards the bottom of the room to replace the hot air that has risen. As the colder air approaches the heater at the bottom of the room, it becomes warmed by the heater and begins to rise (Figure 1.7). Once more, convection currents are slowly formed naturally. Air travels along these pathways, carrying energy with it from the heater throughout the room.

Figure 1.7: Convection currents in a room with an electric heater

Convection currents occur in many places and on varying scales; from huge convection currents in the atmosphere and oceans, to smaller convection currents occurring in a cup of hot tea, domestic hot water cylinder or a hot air balloon.

http://www.seai.ie/Schools/Post_Primary/Subjects/Physics/Unit_6_-_Heat_Transfer/Convection/
Although convection/circulation currents will occur naturally, the process can be assisted with the introduction of a fan or pump. In such a case, the gas/fluid is forced in a particular direction to assist the natural circulation and is known as **forced convection**. Typical examples of forced convection would be the use of a pump as part of a hot water domestic heating system or fan-assisted air curtains at the entrance to a shopping centre.

Heat loss calculations as a result of convection currents in leaky buildings can be as much as half the overall heat lost from buildings. Air infiltrations and uncontrolled ventilation are the primary source of such losses and the rate is quantified by examining the amount of air that leaves the building per hour (Air changes per hour). The rate of heat loss through uncontrolled air movements is directly proportional to the temperature difference between inside and outside and may also be affected by the wind direction, orientation of the building as well as the position of surrounding structures and landscapes.

**Radiation**

To “radiate” means to send out or spread from a central location. The transfer of heat by radiation involves the carrying of energy from an origin to the space surrounding it. The energy is carried by electromagnetic waves and does not involve the movement or the interaction of matter. Radiant energy moves in a straight line at a very high speed and can be absorbed, transmitted or reflected.

**Radiation is the transfer of heat by means of electromagnetic waves**

Thermal radiation can occur through matter or through a region of space that is void of matter (i.e., vacuum). In fact, the heat received on Earth from the sun is the result of electromagnetic waves travelling through the void of space between the earth and the sun. Radiation can be emitted in many forms such as radio waves, microwaves, infrared waves, visible light, ultraviolet waves and x-rays, not all of which are visible to the human eye. All objects radiate energy in the form of electromagnetic waves and the rate at which this energy is released is proportional to the temperature so the hotter the object, the more it radiates. Objects will radiate energy as infrared waves which are not visible to the human eye but an infrared camera is capable of detecting such radiation in the form of thermal photographs or videos (Figure 1.8).
The coils of an electric toaster are considerably hotter than room temperature and emit electromagnetic radiation in the visible spectrum. Fortunately, this provides a convenient warning to its users that the coils are hot but conversely, the energy emitted in heating objects in a microwave oven are not visible.

Heat transfer by radiation is possible as the electromagnetic radiation emitted from the source carries energy away from the source to surrounding or distant objects. This energy is absorbed by those objects, causing their temperatures to rise. In this sense, energy is transferred from one location to another by means of electromagnetic radiation.

A material’s ability to absorb or reflect radiated energy will depend on the type (frequency) of radiation and will also be affected by the surface finish colour and shape of the material. Objects that are good emitters of thermal radiation are also good absorbers. Dark dull colours will tend to absorb and emit thermal radiation better than light shiny colours which tend to reflect thermal radiation. Thin flat surfaces will also absorb and radiate heat faster than thicker rougher surfaces.

1.4 Heat Transfer in Buildings

The average daily temperatures recorded in Ireland for the past 50 years would indicate a seasonal variance from 1°C to 20°C, which is by no means extreme at
either end of the scale. The maximum and minimum recorded temperatures however broaden this seasonal variance out from -12°C to 30°C (Figure 1.10).

![Monthly Air Temperatures - Ireland](image)

**Figure 1.10:** Monthly air temperatures in Ireland - Values courtesy of *Met Eireann* (The Irish Meteorological Service)

For the purpose of energy performance assessment in Dwelling Energy Assessment Procedure (DEAP), ambient room temperatures values recommended for living areas are considered at 21°C and bedrooms at 18°C. The difference between ambient room temperatures and average seasonal air temperatures places the emphasis in Ireland to that of heating rather than a cooling requirement in order to maintain comfortable room temperatures. As average maximum seasonal air temperatures in Ireland do not normally exceed ambient room comfort levels, energy used for cooling buildings is quite small compared to that in, say, Mediterranean countries.

Building construction techniques and standards in Ireland have evolved over the years, mainly stemming from efforts to address space heating requirements. In order to understand how new standards can be more effective in maintaining comfortable room temperatures, it is important to understand why and how the buildings performance affects room temperatures.

The 2nd law of thermodynamics states that heat energy can only move from areas of higher temperature to areas of lower temperature spontaneously (inside to outside).
The 0th law states that, such movement will continue until the areas are in equilibrium. Air temperatures in Ireland are predominantly well below the 18-21°C desired for internal thermal comfort and this would explain why, upon heating a room to the desired ambient temperature the room temperature drops once again when the heating system is turned off.

The energy required for space heating cannot be created but must be converted from some other source as stated in the 1st law of thermodynamics - The total energy remains the same and can only be redistributed or changed from one form to another. Normally, energy is initially converted by burning fuel and the heat transfer which is governed by the laws of thermodynamics can occur through conduction, convection and radiation. A typical central heating system may utilise all three modes of heat transfer to gradually increase the ambient air temperature (Figure 1.11).

![Sealed wet central heating system](Source: SEAI)

- Heat transfer occurs in the boiler by **conduction** through the heat exchanger to the water in the distribution pipes of the system
- Heat is emitted to a room by **radiation** from the heat emitter (radiator)
- Hot water is pushed through the distribution pipes by the circulation pump to the radiators (forced **convection**)

**Figure 1.11: Sealed wet central heating system (Source: SEAI)**

Just as the air temperature is increased by the heating system, the heat energy in the air is lost to the surrounding surfaces and eventually to the outside through conduction, convection and radiation due mainly to the temperature difference and air movements between inside and outside. This is illustrated in Figure 1.12 with the example of heat loss at a window.
The heat loss from a building can be divided into two main categories:

- **Fabric heat loss** - heat loss as it is transmitted through the fabric of the building.
- **Ventilation heat loss** - heat loss through air change, i.e. ventilation and air leakage.

The main factors which affect the scale and rate of heat loss from buildings are:

**Difference between inside and outside temperatures**

Heat loss occurs at a higher rate during winter months due to a greater difference between internal and external temperatures.
Exposed area of the building perimeter

The building envelope is the line of separation between the inside and outside environments of a building. The shape and layout of the building can impact on the rate of heat loss due to greater areas of surfaces exposed at the perimeter. Figure 1.13 shows an example of two buildings with identical floor areas but one has a much greater exposed perimeter which will greatly affect the levels of heat loss experienced.

![Diagram showing comparison between Building A and Building B](https://example.com/diagram.png)

Figure 1.13: Irregular shaped buildings have greater heat loss (Reproduced from S.R. 54:2014 with the permission of NSAI)

The thermal resistance of the external building fabric elements

The rate of heat loss through the building fabric is dependent on the thermal properties and the thickness of the materials used in the construction. The installation of such materials will also become a major factor in the performance on the structure over the lifetime of the building.

Air tightness

Uncontrolled movement of air though leakage paths in the construction will contribute to higher rates of heat loss as well as cold spots and draughts.

Heat is lost from buildings at different rates depending on both the structure and shape (Figure 1.14). With more than 80% of the total energy cost being attributed
to space and water heating, these losses, not only contribute to poor comfort levels within the dwelling but can become very costly over the life of the building.

Figure 1.14: Typical proportions of heat loss from dwellings (source: Tipperary Energy Agency5)

Heat loss in buildings will occur through convection, conduction and radiation, but the rate of this loss can be controlled through the use of appropriate construction materials and techniques in establishing and maintaining an airtight building envelope incorporating high levels of insulation in the application of the building standards.

5 http://tea.ie/oldsite/services/your-home/retrofitting-your-home/
1.5 Heat Gain in Buildings

A building can gain heat from sources both inside and outside the structure. Internal heat gains that come from sources inside the building include the heat given off from ovens, appliances, electronic devices, lighting and by people. But mostly, a building gains heat from its exposure to sunlight, from solar radiation and from infiltration of warmer outside air. The sum of all of this heat accumulation is known as the heat gain of the building.

“Part L - the requirement - L1: A building shall be designed and constructed so as to ensure that the energy performance of the building is such as to limit the amount of energy required for the operation of the building and the amount of carbon dioxide (CO₂) emissions associated with this energy use insofar as is reasonably practicable.”

For new dwellings, the requirements of L1 shall be met by:

(c) Limiting heat loss and, where appropriate, availing of heat gain through the fabric of the building;

Solar gain

The term solar gain refers to the benefits derived from sunlight falling on a surface. It is a heat gain as a result of solar radiation and is a direct result of our proximity and orientation to the sun. Sunlight can heat a space through the walls and roof of the building envelope. Sunlight also enters the space through windows, and heats interior surfaces.

The sun's light and radiated heat is absorbed by surfaces which causes the temperature to increase in those materials. These materials in turn give off heat through direct conduction by warming air which in turn carries heat through convection, and by re-radiating their heat. In the design and orientation of the building, it is important to be able to control the impact of these gains.
For countries in the northern hemisphere, the sun follows an arc across the southern sky rising in the east and setting in the west. The arc is higher in summer months than in winter months resulting in more daylight hours and higher temperatures during summer.

The design, orientation, colour and position of the building, the materials used for construction, along with the size and position of windows will all contribute to the overall amount of solar gain experienced. The objectives in relation to controlling the impact of solar radiation should be to:

- Maximise solar gain in winter to offset heat losses
- Limit solar gain in summer to prevent space overheating
- Ensure minimal interference with natural daylight
- Ensure minimal interference with natural ventilation

The two main approaches to controlling the impact of solar radiation in the design and construction of buildings are:

1. Minimise entry of solar radiation - Primarily through the use of shading and proprietary glazing.
2. Maximise the benefit of solar radiation that does enter - Using thermal mass to absorb the daytime energy and night cooling to remove it.

**Heat Gain through Glazing**

The orientation and size of windows is a huge contributor to the amount of heat that is gained from solar radiation. Temperature and intensity variances between Summer/Winter and day/night will also determine the level of this contribution. It is important to consider that windows responsible for large solar gains during the daytime and during summer may also be responsible for significant heat losses during night time and during winter. (Figure 1.16).
Solar radiation enters glazing by direct, diffuse and reflected paths before being absorbed by elements in the room which in turn heat up (Figure 1.17). These elements will then give off heat which can be positive during winter but may lead to overheating during summer.
The use of shading along with specialised types of glazing can be used to control the rate and impact of solar gains as well as helping to maintain optimum daylight benefit for natural lighting. Different kinds of glazing can be used to draw the sun's heat into the interior, reject it, or allow interior heat to escape.

The number of panes of glass, internal coatings, colour tints, gaps between panes and gasses between panes all affect daylight and radiation transmittance.

In Ireland, solar gain is optimised through the positioning of glazing for living areas in a south facing orientation, thereby maximising the potential heat gain where it can be most useful. Shading can be used to block excess sun at warmer times and allow the sun's heat in at cooler times (Figure 1.18).

Figure 1.18: Illustration of shading between summer and winter.

In the context of passive solar building design, the aim of the designer is normally to maximise solar gain within the building in the winter, in an effort to reduce space heating demand and to control it in summer to minimise cooling requirements. Thermal mass may be used to even out the fluctuations during the day, and to some extent between days.

**Thermal Mass**

Thermal mass is the ability of high density materials such as concrete, bricks and tiles to absorb heat energy. High density materials require a large amount of energy to change their temperature. These materials also retain heat thus slowing the rate at which the sun heats the internal space and the rate at which the space loses heat.
when the sun is gone. Without thermal mass, heat that has entered a space will simply re-radiate back out quickly, with the potential of making the space overly hot during summer and overly cold in winter.

If the element is thermally massive, it will absorb the solar energy striking it and delay the entry of this energy into the room for a number of hours (see Figure 1.9). If there is sufficient thermal mass it may delay the entry of energy until night time when cooler outside air can be used to cool the structure. If the element is thermally light the solar energy heats up the external surface and this energy is quickly transferred through the structure resulting in rise in internal air temperature.

Figure 1.19: Effect of thermal mass and shading for optimising solar gain in winter

If the element is thermally massive, it will absorb the solar energy striking it and delay the entry of this energy into the room for a number of hours. If there is sufficient thermal mass it may delay the entry of energy until night time when cooler outside air can be used to cool the structure. If the element is thermally light the solar energy heats up the external surface and this energy is quickly transferred through the structure resulting in rise in internal air temperature.

Careful consideration to the use of high density building materials is warranted in the design of a building. There is potential to contribute to the thermal comfort levels of a building with solar heat gain without additional construction costs.

### Shading

The energy density of daylight and sunlight varies over a huge range, primarily depending on the time of year, time of day and density of cloud cover. The rate at which this energy is absorbed by the building through glazing and thermal mass must be controlled to prevent overheating and also glare. Shading can be used as an effective method to block direct solar radiation from entering the building while still...
allowing in sufficient daylight. This is particularly important during summer months when the sun intensity and air temperatures are at their highest (Figure 1.20).

Figure 1.20: General methods of shading windows from summer sunlight
The type of shading will dictate the level of daylight, the view and amount of potential ventilation. Well-designed shading will allow for a positive contribution from solar gain during colder winter months while preventing the building from becoming uncomfortably hot during the warmer summer months.

Horizontal shading, large overhangs or deeply recessed windows are methods designed to reduce the effects of direct solar radiation particularly on south facing windows. These methods are most effective when the sun is highest in the sky and at its most intense, between 11am-2pm during summer months. The shading conversely allows almost all direct sunlight during winter due to the lower trajectory path of the sun during these months.

Direct sunlight on surfaces produces glare and when coupled with dark areas within the space, tends to result in variable light quality with poor distribution. Shutters and blinds can be used in this instance to reflect light up onto white ceilings. This provides diffuse uniform lighting deeper into the room reducing the dependence for artificial light to achieve a more uniform distribution.

Horizontal shading is not particularly effective at reducing solar gain on east or west facing windows due to the lower trajectory of the sun during the early morning and late afternoon respectively. Vertical shading may be used to good effect in these instances however there are a number of alternatives that may also be considered.

Landscaping is an effective and pleasant means of providing shading for buildings. Planned landscape may be used to block out the hot summer sun and allow for solar energy in winter (Figure 1.21). Trees can also effectively deflect cold winter winds, and channel breezes for cooling in summer.

![Figure 1.21: Illustration of seasonal effect of a deciduous tree on solar shading](image-url)
External shading devices are the most efficient thermally because they intercept the solar energy before it has entered the room. Even if energy is absorbed by them, it is not trapped behind the glass and within the building. However, external device carry the disadvantages of being generally more expensive to install and maintain and more difficult to control from inside.

Internal devices for controlling solar gain such as blinds or curtains tend to be least effective due to the fact that energy has already entered the building. However, these devices do reduce the total amount of heat gain as well as contribute positively to the control of glare. Internal shading is generally much cheaper to install, easy for users to control but may be vulnerable to damage.
Summary

- Heat loss in buildings is governed by the laws of thermodynamics. Understanding the mechanisms by which heat transfer results in heat loss is fundamental to understanding how such losses can be minimised.
- Heat loss occurs through conduction, convection and radiation, and is driven primarily by the difference between inside and outside temperatures. The rate of heat loss can be minimised by employing design and construction techniques to address each mode of heat loss.
- Heat losses through conduction can be directly attributed to the materials used in the construction of the fabric of the building. Some materials will have a natural tendency to resist the passage of heat while others will promote it. For this reason, it is important that buildings are designed and constructed using materials which provide a high degree of insulation thus minimising heat losses through conduction. The shape and size of the building will also contribute to conduction heat loses due to the proportional area exposed to external elements.
- Convection heat losses due to air movement can be attributed to the number of air leakages and degree of uncontrolled ventilation within the building. As up to half of heat lost in buildings can be due to this mode of transfer, building with an air-tight and wind-tight focus is essential to an energy efficient design.
- Heat loss/gain due to radiation also involves a temperature difference. As this will be seasonal and dependent mainly on the position and intensity of the sun, the design and orientation of the building is critical, particularly in relation to glazed areas and the thermal mass of materials in exposed spaces. The sun's energy can be used to naturally heat and light a building reducing the requirement for artificial light and heat.
- It is possible to significantly reduce the energy requirement of a building through its design, layout and orientation.

Further Reading

1. Define the term thermodynamics

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________

2. State the 3 laws of thermodynamics that relate to building fabric
   1) __________________________________________________________
       __________________________________________________________
       __________________________________________________________
   2) __________________________________________________________
       __________________________________________________________
       __________________________________________________________
   3) __________________________________________________________
       __________________________________________________________
       __________________________________________________________

3. Describe 3 factors which affect the flow of heat between two bodies.
   1) __________________________________________________________
       __________________________________________________________
       __________________________________________________________
   2) __________________________________________________________
       __________________________________________________________
       __________________________________________________________
   3) __________________________________________________________
       __________________________________________________________
4. Describe the following mechanisms for heat flow:

1) Conduction: __________________________________________________________
   __________________________________________________________
   __________________________________________________________

2) Convection: __________________________________________________________
   __________________________________________________________
   __________________________________________________________

3) Radiation: __________________________________________________________
   __________________________________________________________
   __________________________________________________________

5. Describe the difference between a conductor and an insulator, and give an example of each stating their typical λ-values.

   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________

Conductor: ________________________________ λ-value __________

Insulator: ________________________________ λ-value __________

6. Based on the average monthly air temperatures recorded by Met Eireann, state the range of months where there would be a heating requirement based on DEAP ambient room temperatures.

   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________

7. What is the difference between heat gain and solar gain?

   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________
   ________________________________ ________________________________
8. Describe how buildings loose heat and list 4 factors that affect the overall rate of heat loss.

_____________________________________________________________
_____________________________________________________________
_____________________________________________________________
_____________________________________________________________

1) _______________________________________________________
2) _______________________________________________________
3) _______________________________________________________
4) _______________________________________________________

9. List 4 objectives for controlling the impact of solar gain

1) _______________________________________________________
2) _______________________________________________________
3) _______________________________________________________
4) _______________________________________________________

10. Describe how materials with a large thermal mass contribute to internal heat gains

_____________________________________________________________
_____________________________________________________________
_____________________________________________________________
_____________________________________________________________
_____________________________________________________________
Unit 1 Section 2

Air Permeability and
Thermal Bridging
2.1 Introduction

Uncontrolled air exchange through gaps, cracks and holes in the fabric of a building can account for over 30% of all heat loss in a domestic dwelling. Outside of the specific installation of air control layers in building fabric construction, there are a range of activities carried out onsite by different trade’s which can affect the air permeability levels in a building. Therefore, every building construction worker should be aware of their responsibilities for maintaining the structural air tightness of the building envelope.

TGD Part L 2011 for Dwellings states that “air pressure testing should be carried out on a proportion of dwellings on all development sites including single dwelling construction……. to show attainment of backstop value of 7 m³/(h.m²)” at 50 Pascal. Actual experience onsite is indicating that achievement of the prescribed energy and carbon performance coefficients in the regulations generally require a level closer to 5 m³/ (h.m²). From having no set minimum standard for air permeability until 2008, when the 10m³/ (h.m²) level was introduced, we now have a standard which is effectively half this again and subject to an onsite testing regime.

Any worker who has a role at any stage in the development of the building fabric, i.e., bricklayers, carpenters, plasterers, plumbers, electricians, glaziers, painter and decorators, floor and carpet layers, and all other variants of crafts workers listed here including operatives have a reasonability to ensure air tightness is not compromised.

A similar level of responsibility applies when it comes to the buildings’ thermal envelopes. Thermal bridging occurs in a building envelope when gaps or breaks in the insulation envelope create pathways for heat energy to bypass thermal insulation. This heat loss is significant in terms of energy costs but also has other adverse implications relating to condensation on the surface of and within building fabric.

At the end of this section you will be able to:

1. Outline the principles of airtight construction and identify common air leakage pathways in buildings.
2. Explain the impact of thermal bridging on energy performance in buildings and illustrate good practice examples of detailing to mitigate its effects.
3. Describe the relationship between ventilation, vapour control, thermal mass and surface /interstitial condensation in building fabric.
2.2 Ventilation versus Air Infiltration

Ventilation is the controlled supply of outside fresh air to a building by natural and/or mechanical systems. Air infiltration, on the other hand, is the uncontrolled entry of fresh air into a building through air leakage paths, e.g. gaps at junctions between external building elements and around openings, and unsealed penetrations of the building envelope.

A fundamental principle of low energy building is to build tight, thereby minimising the possibility of transfer of heat energy through the external fabric. However, appropriate air-change levels must be provided by a ventilation system to maintain air quality for the building’s occupants and reduce the risk of condensation. It is important for all those involved in the construction and renovation of buildings to understand these basic principles.

Ventilation

Ventilation is required in dwellings in order to allow fresh air in and stale air out. This is to ensure that the air quality in the building is to acceptable standards. The Building Regulations for ventilation\(^6\) define the requirements for means of ventilation as follows:

\[
\begin{align*}
\text{Means of Ventilation - F1} \\
\text{Adequate means of ventilation shall be provided for people in buildings. This shall be achieved by:} \\
\text{a) limiting the moisture content of the air within the building so that it does not contribute to condensation and mould growth, and} \\
\text{b) limiting the concentration of harmful pollutants in the air within the building.}
\end{align*}
\]

TGD Part F 2009 also describes how this controlled ventilation can be achieved through:

- rapidly diluting pollutants, including odours, and water vapour to levels which do not pose direct or indirect health risk;
- removing excess water vapour from areas where it is produced in significant quantities, such as kitchens, utility rooms, bathrooms and shower rooms so as to reduce the likelihood of creating conditions that support the growth of mould, harmful bacteria, pathogens and allergens;
- removing harmful pollutants from areas where they are produced in significant quantities;
- providing an adequate supply of fresh air for persons using an area in a building;
- dispersing residual pollutants and water vapour.

The types of air pollutants in buildings that a ventilation system are required to disperse can be broadly categorised as either activity based or environment based.

**Activity Based Airborne Pollutants**

- **Moisture** – steam from cooking/bathrooms, moisture from respiration
- **Carbon Dioxide (CO₂)** – from occupants respiration
- **Carbon Monoxide (CO)** – from incomplete combustion of fossil fuels
- **Smoke** – from tobacco smoke, open fires and solid fuel stoves
- **Odours** – from cooking and body odour

**Environment Based Airborne Pollutants**

- **Volatile Organic Compounds (VOCs)** – a substance containing carbon that evaporates at room temperature. Found in some building and household materials can be sources of VOCs, e.g. new carpets, wood products that use particular adhesives, paints and lacquers
- **Allergens** – such as house dust, mould and dust mites
- **Radon** – a naturally occurring radioactive gas that occurs to some degree in all soils and rocks. The gas can permeate into a building from the subfloor.
- **Particulate Matter (PM 10s)** – miniscule sooty particles, mainly originating from motor vehicle traffic often entering buildings through open vents
Of all the pollutants, control of moisture (water vapour) requires the highest ventilation rate. If a sufficient quantity of fresh air is supplied to control water vapour then dilution of the other pollutants will be catered for. Figure 2.1 illustrates the moisture generation for four people occupying a dwelling.

![Moisture Generation](image)

Figure 1.22: Typical moisture generation levels in a dwelling (adapted from BS 5250:2002)

Traditionally in Irish dwellings, controlled ventilation is provided naturally by means of background ventilators (hole in the wall/window trickle vents), see Figure 1.23.

![External wall vent cover and section through wall vent](image)

Figure 1.23: External wall vent cover and section through wall vent (Source – TGD Part F 2009)

Alternative systems to natural background ventilation are increasingly being deployed in Irish buildings. In recognition of this, TGD Part F2009 was the first to include guidance for systems such as passive stack, mechanical ventilation and mechanical heat recovery ventilation (MVHR). These systems can provide more control over the amount of air changes than background ventilation alone. MVHR can allow for heat
recovery exchange between the outgoing warm air and the fresh incoming cold air, thus negating any heat loss due to ventilation by recycling the energy that has been already used to heat the air inside of the building.

### Causes of Air Infiltration

TGD Part F 1.1.2 p 5 states, “Air Infiltration is the uncontrollable air exchange between the inside and outside of a building through a wide range of air leakage paths in the building structure.”

Air infiltration is affected by design and quality of construction and by wind speed/direction:

1. **Wind Effect:** Wind against the dwelling causes pressure differences between the inside and outside (Figure 1.24). Air is drawn into the dwelling through gaps on the windward face (infiltration) and leaves the dwelling on the leeward face (exfiltration).

![Figure 1.24: Wind Effect causes pressure differences](source: GPG 268 Energy efficient ventilation in dwellings Energy Saving Trust, 2006)

2. **Stack Effect:** Warm indoor air is more buoyant than colder outside air, therefore warm air rises by convection (Figure 1.25).

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7 TGD Part F
a. This effect draws in cooler air from outside (infiltration) which is felt as cold draughts inside.

b. The rising effect increases the pressure inside the dwelling which pushes warm air out of cracks and gaps in the envelope (stack effect).

Figure 1.25: Stack Effect warm air rises by convection (source: GPG 268 Energy efficient ventilation in dwellings Energy Saving Trust, 2006)

Infiltration or uncontrolled air exchange should be kept to an absolute minimum. Air tightness standards have been set out in TGD Part L 2011 (1.3.4 Building Envelope Air Permeability). When an air pressurisation test is carried out in order to measure air permeability, all of the controlled ventilation points in the dwelling are sealed, e.g. wall/window vents, mechanical extract vents, fans, open flues/chimneys.

Air permeability test measures only the uncontrolled air exchange in the building. Figure 1.26 highlights the most common areas for consideration when trying to minimise air infiltration. It is important that all workers involved in the construction/renovation process are aware of the common problem areas and their impact on energy consumption. Adequate ventilation is essential, and as we build tighter buildings, correct ventilation levels need to be installed and maintained to ensure comfort and safety of occupants.

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Figure 1.26: Common areas to consider when trying to minimise air infiltration

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8 TGD Part L 2011
Figure 1.26: Common air leakage pathways in a dwelling (source: Improving airtightness in dwellings, Energy Saving Trust, 2005)

2.3 Air Tight Construction

The basic principle of airtight building is in the formation of a continuous airtight envelope to minimise air leakage. Building regulations technical guidance for dwellings includes an accompanying document entitled “Limiting Thermal Bridging &
Air Infiltration - Acceptable Construction Details™ (ACDs). Section 1 of the ACDs provides guidance for establishing an air tightness strategy in order to ensure continuity of the airtight envelope which is summarised in the following sections.

At Building Design Stage

- Simplify built form where possible.
- Define the line of the air barrier as early as possible. Mark up large scale sections with a bold coloured line (see Figure 1.27).

![Figure 1.27: Defining the air tight envelope on a building section](http://www.environ.ie/en/Publications/DevelopmentandHousing/BuildingStandards/FileDownload,18749,en.pdf)

- Consider and rationalise construction sequencing.
- Redefine the air barrier route and insulation strategy in critical areas to simplify details and avoid problems.
Decide and specify which materials will form the air barrier. Consider:

- Material air permeability
- Buildability/practicability
- Position within the construction
- Long term durability

Consider junction details between air barrier materials:

- Practicality of forming the seals on site
- Durability of the seals, especially where not accessible for future remedial work.

Best practice is to minimise the number of service penetrations through the external wall. Consider how service penetrations will be sealed. Rationalise service routes and penetrations. Highlight air barrier critical elements and junctions on construction drawings (see Figure 1.28). Apportion responsibility for sealing critical junctions to specific trades.

Figure 1.28: Checklist for Air Barrier Continuity, Ground Floor Insulation above slab (source: ACD Section 2, Cavity Wall Insulation)
At Construction Stage

Agree responsibility for management of air-tightness, covering coordination and inspection of the overall formation of the air barrier. Brief the whole construction team (not just management) on the need for and importance of the air barrier. Inform the team of the air barrier line, the materials which will form the barrier and the critical junctions. Encourage operatives to draw attention to unforeseen difficulties rather than using makeshift solutions.

All workers onsite need to know this information and be aware of the ramifications of their actions should they interfere or come in contact with the air barrier at any stage of the build process.

Air barrier management to undertake:

- Coordination of the formation of the air barrier
- Site quality assurance
- Check and sign off all “hidden” air barrier elements before covering up.

Review the construction as work proceeds to identify any weaknesses in the air barrier strategy/areas not previously considered and feed this information back to the design team. Establish solutions to any problems identified. Undertake airtightness testing at the earliest possible opportunity. Use an established pressure testing company for accurate diagnostic feedback. All materials and workmanship, including air-tightness tapes and sealants, should be supplied and completed as per guidelines in Technical Guidance Document D\textsuperscript{10}. ACD Section 1 2008 p.14\textsuperscript{11}

How to achieve air tightness

Air tightness means cutting out unwanted air leakage. While some leaks can be so slight as to be imperceptible, even slight draughts will increase heat loss and reduce comfort levels, sometimes dramatically. Air Tightness requires attention to detail for new build situations. For retrofitting it is more challenging to achieve air-tightness but it is possible through the application of particular approaches and systems.

\textsuperscript{10} TGD Part D

\textsuperscript{11} ACD Section 1
Points to watch:

- Plaster between the joists at suspended timber floors.
- Make sure there's no gap along the skirting's at floor level.
- Where pipes or wires pass through the outside wall or the roof, seal around them to draught-proof the penetration.
- Tape around window and external door frames to prevent air leakage at junctions with walls and floors. Appropriate air tightness tapes can be used to seal between the wet plastered finish of the wall and the window frame.
- Seal all penetrations through air barrier using an appropriate air tightness flexible sealant or tape.

“I can't pass it as a dwellable cave unless you get yourself a rollable boulder to reduce your heat loss.”
2.4 Thermal Bridging

Section 2.3 highlighted the responsibility of all workers on site towards ensuring the continuity of the air barrier. The same level of responsibility applies when it comes to the building's thermal envelope. In most part, thermal bridging can be avoided by craft workers paying close attention to detailing at junctions and service penetrations of the external fabric of the building.

Thermal bridging occurs in building envelopes when gaps or breaks in the insulation envelope create pathways for heat loss to bypass thermal insulation. Thermal bridging also occurs in building envelopes when materials with higher thermal conductivity/K value or what is commonly known as the $\lambda$ (Lambda) value are used. When materials such as steel, timber and concrete are used they can create pathways for heat to bypass the thermal insulation, as the heat always looks for the path of least resistance.

This symbol $\Psi$ (Psi value) is used to denote the linear thermal transmittance or heat loss associated with a thermal bridge. It is the rate of heat flow per degree per unit length of the bridge and is measured as additional heat loss to the fabric losses through plane elements. The shorter the bridge or pathway, the quicker the rate of heat loss. In Figure 1.29 the bridge on the right hand side of the diagram is longer, and leading to a lower rate of heat loss.

![Figure 1.29: Two variations of a Thermal Bridge at wall and floor junction](image)

Implications for heat loss and comfort

Continuity of the thermal envelope minimises the rate of heat flow from the building. As heat loss cannot be avoided what is required is a constant slow rate of heat flow through the entire fabric. Thermal bridging causes increased heat flow in different parts of the building fabric, meaning that it is harder to predict how much energy will be needed to maintain a comfortable temperature within. Therefore heat loss calculations need to include thermal bridging calculations.
Cold bridging is basically cold areas on the internal surface of the envelope and, as we know from the Second Law of Thermodynamics, heat energy flows from areas of higher temperature to areas of lower temperature. The heat within the building is already trying to flow to the lower temperatures outside but this flow rate is dramatically increased through the cold spots. When there are fluctuations or changes in temperature caused by hot air inside trying to move outside, this creates air currents (Figure 1.30).

![Figure 1.30: Temperature driven flow creates air currents within the building (Source GPG 268 Energy efficient ventilation in dwellings Energy Saving Trust, 2006)](image)

These air currents within the building which are increased especially around cold areas are experienced as drafts by the occupants and will negatively affect comfort level. This usually results the occupants turning up or boosting the heating simply because of the discomfort caused by the draft from the cold bridging. Eliminating the cold bridging as much as possible could reduce the drafts and increase the level of comfort for the buildings occupants, and with less or no energy wastage.

Surface & interstitial condensation and air quality considerations

TGD Part L states that, “To avoid excessive heat losses and local condensation problems, reasonable care should be taken to ensure continuity of insulation and to limit local thermal bridging, e.g. around windows, doors and other wall openings, at
junctions between elements and other locations. Any thermal bridge should not pose a risk of surface or interstitial condensation." ¹²(TGD Part L pg. 17)

The colder the air, the less water vapour it can hold. For example, if the room temperature is 20°C and the humidity level is measured at 50%, then the air is holding half of its maximum amount of moisture. As the temperature is lowered in the house the humidity level will rise. If the humidity level reaches 100% and the temperature is still falling, condensation begins. This condensation can form where thermal bridging has created cold areas on the internal surface of the building. Warm moisture laden air condenses on cold surfaces thereby increasing dampness.

Water vapour in the air is absorbed by surrounding materials, including the materials that make up the building fabric. However as vapour passes through the fabric of the building and where the temperature is dropping inside of the fabric the vapour will reach Dew Point and start to condense at a location within the wall fabric (see Figure 1.31). An understanding of the Dew Point and condensation is particular relevant for retrofitting insulation e.g. dry-lining applications.

Figure 1.31: Section through external wall illustrating the Dew Point

¹² TGD Part L 2011
Leakage of warm damp air through the building structure can lead to condensation within the fabric (Interstitial Condensation), which can reduce insulation performance and cause fabric deterioration.

If the relative humidity levels in the building exceed 70% for prolonged periods, there is a high probability that the condensation occurring on cold surfaces will lead to mould growth\(^\text{13}\) (see Figure 1.32). This can seriously affect the quality of the air for the occupants and mould spores can have a detrimental effect on human respiratory system. Therefore, thermal bridging can lead to condensation and possibly mould growth.

Figure 1.32: Black mould, known as Stachybotrys chartarum, at a window reveal

Condensation and mould growth may be avoided by ensuring adequate insulation detailing and provision of suitably controlled ventilation in all parts of a building. However, with interstitial condensation, mould growth can take place within the building fabric structure where it is invisible; hence, cannot be cleaned off, creating an unhealthy living environment for the occupants. Mould spores have a detrimental effect on human respiratory system and with over 470,000 people in Ireland suffering from asthma\(^\text{14}\), this emphasises the importance of managing condensation in building fabric.


\(^{14}\) Asthma Society of Ireland, [http://www.asthma.ie/get-help/learn-about-asthma/asthma-basics/asthma-basics](http://www.asthma.ie/get-help/learn-about-asthma/asthma-basics/asthma-basics)
Repeated versus localised thermal bridging

There are two categories of thermal bridging that occur in buildings and should be accounted for when measuring the performance of building fabric:

- Repeated thermal bridging which occur in the structure of the plane elements
- Localised or non-repeating thermal bridging which occurs at junctions between elements and at openings

Repeated thermal bridge

In some cases the thermal bridge is repeated at given intervals across the external fabric of the building. Two common examples are:

a) Repeated thermal bridging due to steel wall ties in a cavity wall construction (Effect can be negated if using low conductivity plastic wall ties) and
b) Repeated thermal bridging due to mortar joints in block work leafs, see Figure 1.33.

Figure 1.33: Mortar joints in insulated cavity block wall and stainless steel wall ties are common examples of repeating thermal bridging (source: SEAI, Retrofitted Passive Homes, 2009)
The effect of this repeated thermal bridging is included when calculating the overall U-value (thermal transmittance) of the block wall following procedures described in I.S. EN ISO 6946 (see Unit 2 Section 1 for examples). As insulation levels increase the effect of repeated thermal bridges also increase. Whenever the need arises to increase the cavity width to accommodate extra insulation quite often the amount and density of wall ties required must also be increased. This amplifies the effect of this type of cold bridge, and walls U value increases by up to 13% have been recorded\textsuperscript{15}.

**Localised thermal bridging**

Localised thermal bridging is also referred to as a linear or non-repeating thermal bridge. These generally occur around openings in the insulation envelope and junctions between building elements, see Figure 1.34. This thermal bridging does not occur at repeated regular intervals and so cannot easily be calculated as part of the individual wall, roof etc. When insulation is introduced into the fabric of a building it slows down the overall rate of heat loss so our energy consumption is reduced.

Figure 1.34: Thermal image (inset) of a residential building illustrating thermal bridging around openings and junctions

\textsuperscript{15} Low Carbon Housing Learning Zone, Leeds Beckett University
Forty years ago when we had little or no insulation in our homes cold bridging was not a major factor. This is because the entire internal surface of the fabric of the house was more or less equally cold. But as we introduced and increased the amount of insulation in our homes, this in turn amplified the effect of any thermal bridging.

Common thermal bridges may account for up to 30% of the fabric heat loss within dwellings\(^{16}\). This is especially true with newer buildings as there is a requirement for much higher levels of insulation in the building fabric. Therefore, by identifying these cold bridges and eliminating them or minimising their effect, energy loss in buildings may be reduced.

The greater the level of insulation the greater the effect of the thermal bridge. So, now that our building standards are requiring significant levels of insulation, extra attention to detail is needed in order to limit thermal bridging as much as possible. Because heat wants to flow from hot to cold what happens is that the warm moisture laden air in the building gravitates towards the cold areas on the wall, roof or floors. Common areas for this type of thermal bridge include around window and door openings, ceiling, floor and wall junctions and all service penetrations of the fabric.

**Thermal bridging at key junctions & openings**

Thermal bridging will occur wherever the insulation layer in the building fabric is breached, bridged or broken. Thermal bridging can be repeated, e.g., where steel wall ties, timber wall studs, floor joists, ceiling joists and rafters are used. Alternatively, thermal bridging may be localised, e.g., at corners and wall junctions, around window and door openings, where service-ducts, pipes and cables penetrate the outer fabric and around the perimeter of the floor at ground level and the roof at wall plate level.

The following examples illustrate good practice of detailing to mitigate the effect of common cases of thermal bridging. For more detailed specifications, see TGD Part

\[16\] Low Carbon Housing Learning Zone, Leeds Beckett University
L supplementary documents of 2008, on “Limiting Thermal Bridging and Air Infiltration” ACDs Section 2 should be viewed\(^{17}\).

**Example 1: Timber Frame Studs (Repeated Thermal Bridging)**

Consider the heat loss through a timber frame construction as depicted in Figure 1.35. Each resistance layer is made up of two very different materials, timber and mineral wool insulation. The poorer insulator, timber, provides an uninterrupted “short circuit” through the insulation, between the interior and exterior of a building causing a repeat thermal bridge. This reduces the effectiveness of the insulation and increases the overall U value of the wall.

![Figure 1.35: Typical timber frame external wall construction resulting in Repeated Thermal Bridging](image)

To minimise the impact of the thermal bridge, the designer should minimise the area of timber exposed to the warm air inside the heated space, without

\(^{17}\) Limiting Thermal Bridging and Air Infiltration ACD
weakening the structure. This may be achieved by moving part of the thermal bridge so that it is no longer in contact with the warm air inside (Figure 1.36), or to stagger the struts. Also, if possible, the construction detail should be changed to place the timber studs at 600mm centres rather than 400mm centres.

![Additional Insulation Layer](image)

**Figure 1.36: Addition of Insulation Layer to Counteract Thermal Bridging Affect**

**Example 2: Concrete floor perimeter**

Another example of thermal bridging is depicted in Figure 1.37(a), where no perimeter insulation has been used for the concrete floor, creating a continuous flow of heat and energy from the dwelling. Figure 1.37(b) shows the correct detailing for prevention of thermal bridge.

![Masonry Wall, Heat Loss Path, Concrete Floor, Insulation, Hardcore Fill](image)

**Figure 1.37(a): Un-insulated Perimeter Concrete Floor Slab with Dry-Lined External Wall**
Figure 1.37(b): Insulated Perimeter Concrete Floor Slab with Dry-Lined External Wall

Figure 1.38(a) shows a similar thermal bridge where no perimeter insulation has been used for a cavity wall construction which requires more complex detailing to negate.

Figure 1.38(a): Un-insulated Perimeter Concrete Floor Slab with External Cavity Wall
Figure 1.38(b) includes perimeter insulation for the concrete slab which eliminates the thermal bridge at the floor perimeter. However there still remains a thermal bridge at this junction as seen in the diagram.

**Figure 1.38(b): Insulated Perimeter Concrete Floor Slab with External Cavity Wall**

Figure 1.38(c) illustrates how this thermal bridge at the junction of the floor and wall can be reduced considerably by extending the cavity insulation below the level of the floor slab and perimeter insulation.

**Figure 1.38(c): Insulated Perimeter and Extended Cavity Wall Insulation**
Example 3: Cavity closer (window/door vertical jam)

It is a common mistake not to include insulation at the vertical jam of a cavity wall when the cavity is being closed using concrete blocks creating a thermal bridge (Figure 1.39(a)). The insulation layer should be continuous right the way up to the window or door frame as seen in Figure 1.39(b). Alternatively a proprietary insulated cavity closer can be used as a means of closing the cavity, preventing any thermal bridge around the window or door openings as demonstrated in Figure 1.39(c)

Figure 1.39(a): Un-insulated Cavity Wall Closer at Window Reveal

Figure 1.39(b): Insulation Strip installed to Cavity Closer at Window Reveal

Figure 1.39(c): Proprietary Cavity Closer installed at Window Reveal
**Example 4: Dry-lining (window/door vertical jam)**

Hollow block or cavity block wall construction requires similar detailing around openings. If the internal dry-lying is stopped short of the window or door frame, a bridge will be created for heat loss to take place (Figure 1.40(a)).

![Heat Loss Path Diagram](image)

**Figure 1.40(a): Dry-Lined Hollow Block Wall Un-insulated at Window Reveal**

Returning the insulation around the jam of the opening as seen in Figure 1.40(b) will prevent the thermal bridge from occurring. Ideally, this is pre-planned as the thickness of the window or door frame will dictate the thickness of the returned insulation.

![Install Strip of Insulation Diagram](image)

**Figure 1.40(b): Dry-Lined Hollow Block Wall Insulated at Window Reveal**
Example 5: Window sill

Another area where thermal bridging occurs is around window sills. Quite often the window sill is either backed up with sand and cement or concrete. This breaks the continuity of the insulation layer, creating a passage for rapid heat loss (Figure 1.41(a)).

Figure 1.41(a): Cavity Wall Un-insulated Sill Detail

Concrete sills need to be backed with insulation as illustrated in Figure 1.41 (b) and even using this detail there are still a break left in the insulation layer.

Figure 1.41(b): Cavity Wall with Insulation to Back of Sill
In order to eliminate any major thermal bridging from the window sill the cavity insulation needs to be continued behind the sill and up tight to the window frame, Figure 1.41(c). This may require the use of a purpose made sill to accommodate the insulation depending on the width of the overall wall and the cavity.

![Figure 1.41(c): Cavity Wall with Insulated Cavity Closer at Sill](image)

**Using Acceptable Construction Details (ACD)**

In 2008 accompanying documents for TGD Part L were introduced as additional guidance for designers and contractors. The “Limiting Thermal Bridging and Air Infiltration Acceptable Construction Details” include specifications and detailed sectional drawings of junctions and other important areas for consideration for thermal bridging and air infiltration. The details and guidelines developed for use in Ireland appear to have been adapted from UK guidelines. Both also adopt a checklist approach illustrated in see Figure 1.42, in which tick boxes are completed to verify correct installation.

Building to Acceptable Construction Details will reduce heat loss by achieving:

- Less thermal bridging.
- Increased air tightness.
2.5 Principle of continuity of the thermal envelope in a building

The following sections on design and construction stage have been adopted from ACD, Section 1 (2008). Every person involved in construction can help reduce thermal bridging. Specifically, keeping a continuous insulation envelope around the building is important and can be achieved in the following ways:

- Designers should make every effort to specify construction details that minimise thermal bridging and, those details should be as straightforward as possible. This will reduce the likelihood of mistakes onsite and shortcuts.
- Building must be completed as specified.
- Craftsmen taking services through the finished insulation envelope must repair and replace any damaged insulation. They must also ensure that insulation is tightly fitted around the penetration.
Those in charge must inspect and approve all construction details, as the work progresses, and before it gets hidden from view by internal or external finishes.

The air barrier should closely follow the line of the inside face of the insulation in the exposed elements of the fabric of the building (see Figure 1.43). This is to help avoid thermal bypassing through thermal looping and subsequently to help prevent interstitial condensation. **Thermal looping** is where a building may be airtight but if the warm side of the insulation is not protected by an airtight membrane then drafts and air circulating around the insulation will have a cooling effect.

“It is good practice to mark up the air barrier line and insulation layer on the architectural main section drawings as a bold distinguishable line. If the insulation is continuous, it should be possible to trace around the whole section without lifting the pen. If you have to lift the pen, you have discontinuity and a potential for thermal bridging”. (ACDs, Introduction and general theory of insulation continuity and air tightness⁹)

![Figure 1.43: Defining the air tight envelope and insulation layer](http://www.environ.ie/en/Publications/DevelopmentandHousing/BuildingStandards/FileDownload.18749.en.pdf)
At Design Stage

It is best practice to prepare large scale drawings of sensitive points in the building design. These drawings should clearly identify the insulation layer. The drawings should be issued to all relevant parties identifying how the integrity of the insulation layer is maintained at particularly complex interfaces.

Observation of the following points will help achieve insulation continuity:

- Keep it simple! Simple designs are easier to execute.
- Use the pen-on-section test to check continuity and to identify key details.
- Pay careful attention to the design of junctions between elements to ensure continuity of the insulation layer.
- Think the construction sequence of each detail through, to ensure that it can be built. Change details if it becomes apparent they do not work, or if site staff identify better ways of doing them.
- Favour simplicity of form – complex forms increase the number of junctions within the thermal envelope, each of which increases the likelihood of discontinuities.
- Minimise penetrations of the thermal envelope, whether by services or structure or construction. A service cavity inside the air barrier line can help reduce service penetrations.
- Where penetrations are unavoidable (soil stacks, ventilation exhausts and intakes, water supply, electricity and gas supplies), develop appropriate details for their proper execution and for making good any damage to insulation.

At Construction Stage

Three basic principles should be addressed in construction stage to ensure insulation continuity, these are: Management, Communication, and Quality Control.

Management

Continuous review of the design is necessary. The project management should ensure that details of all design changes involving elements of the external envelope are highlighted to the design, procurement and construction teams.

It is important that the project programme reflects the required sequence for effective formation of the insulation installation, e.g., eaves insulation. All trades
persons must be permitted access to form not only the part of the insulation layer for which they are responsible, but also to ensure that continuity is achieved between their works and that of other contractors.

**Communication and Education**

Personnel involved in procurement and constructing the building fabric should understand the need for insulation continuity. The more aware people are of the issues, the less likely essential components omitted from the design for cost savings, and the more receptive site staff will be to requests for a higher standard of workmanship.

Awareness may be raised at key stages by briefing procurement offices and site tool-box talks. The detailed pen-on-section drawings may be issued to all parties clearly identifying where and how insulation continuity will be maintained.

Operatives directly involved in installing the insulation layer should be encouraged to draw attention to difficulties and request direction rather than taking responsibility for decision-making themselves.

Operatives who may not be directly involved in the building fabric should also be made aware of the importance of insulation continuity and of flagging up any breaches through these “lines of defence”. They should also be required to remedy potential thermal bridges brought about by their own activities, or to seek help from other trades, depending on the nature of the breach.

**Quality Control**

Many contractors now have systems in place for monitoring the quality of their processes and products. Experience shows that the Quality Assurance (QA) should be extended to check for insulation continuity. The Acceptable Construction details can be used as guidance for this.

An essential QA control is that insulation continuity and airtightness are considered during all design changes and material substitutions affecting the external envelope. An ill-formed design change may jeopardise the final performance of the building envelope.

The QA process should ideally involve inspection of finished works especially the building envelope. This will enable management to check that all works are properly constructed prior to being covered over.
**Summary**

- One of the main potential areas for heat loss in a building is the uncontrolled air exchange from inside and outside of the building. Current building regulations set a requirement for air pressure testing of new dwellings. This should reduce domestic energy consumption and waste *provided that all persons involved in the design and construction process know what the requirements are, and consequently work together to achieve them.*

- Current standards for dwellings set an air permeability level of 7 m³/hr/m² at 50 Pascal. However, future revisions of the regulations are likely to require some form of mechanical ventilation system to be included to achieve performance compliance. An air permeability standard of 3 m³/hr/m² maximum is required to accommodate efficient operation of such systems.

- With current backstop U-values in building regulations close to passive house standards, substantial levels of insulation are required for compliance. In order to actually achieve these U values in practice, the insulation needs to be installed correctly.

- Insulation should be tightly fitted to the fabric with no gaps and should form a continuous layer around the building fabric, with minimal penetrations so as to avoid thermal bridging.

- With increased levels of insulation, the affect any thermal bridging has on the building is amplified. Thermal bridging potentially leads to surface condensation and/or interstitial condensation, as well as increased energy usage.

- Attention to detailing in the design and construction stage is paramount as is communication between all workers onsite in order to achieve a quality product which meets the current high level of building standards.
Further Reading


M1.U1.S2 Progress Check

1. What is the recommended number of (ach) for a whole dwelling in order to control condensation?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

2. List eight reasons why ventilation is important to the structural integrity of a dwelling and the health and wellbeing of its occupants.

1) _____________________________________________________________
___________________________________________________________________
2) _____________________________________________________________
___________________________________________________________________
3) _____________________________________________________________
___________________________________________________________________
4) _____________________________________________________________
___________________________________________________________________
5) _____________________________________________________________
___________________________________________________________________
6) _____________________________________________________________
___________________________________________________________________
7) _____________________________________________________________
___________________________________________________________________
8) _____________________________________________________________
___________________________________________________________________

3. List and give a brief description of the two causes of air infiltration and exfiltration.

1) _____________________________________________________________
___________________________________________________________________
2) _____________________________________________________________
___________________________________________________________________
4. List five materials that are unsuitable for managing air tightness in the building fabric.

1) _____________________________________________________________
2) _____________________________________________________________
3) _____________________________________________________________
4) _____________________________________________________________
5) _____________________________________________________________

5. List ten common areas of a building where air infiltration and exfiltration may occur.

1) _____________________________________________________________
2) _____________________________________________________________
3) _____________________________________________________________
4) _____________________________________________________________
5) _____________________________________________________________
6) _____________________________________________________________
7) _____________________________________________________________
8) _____________________________________________________________
9) _____________________________________________________________
10) _____________________________________________________________

6. Determine the current air permeability standard at 50 Pa as set out in TGD L Part 2011 for Dwellings.

___________________________________________________________________
___________________________________________________________________

7. What is a pen-on-section drawing?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
8. List some good practice guidelines to follow when establishing an air tightness strategy for a new building.

___________________________________________________________________
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Unit 2

Measuring Building Fabric Performance

Co-funded by the Intelligent Energy Europe Programme of the European Union
As indicated in Unit 1, there are a number of areas that affect the overall performance of the building fabric including U-value of plane elements, thermal bridging and air permeability. The building regulations provide guidance on calculation of U-values and accounting for thermal bridging. The Dwelling Energy Assessment Procedure (DEAP) requires the input of information such as U-value and thermal bridging factors to determine the performance of the building envelope.

This unit provides an overview of the calculations referred to in TGD Part L, providing explanations and examples to illustrate their application. Guidance is also provided on the use of DEAP to calculate building fabric performance.

At the end of this unit you will be able to:

- Calculate U-values for typical simple fabric constructions
- Describe the methods outlined in TGD Part L 2011 to account for thermal bridging in U-value calculation
- Input appropriate information to the Ventilation and Building Elements sections in DEAP software
Unit 2 Section 1

Heat Loss Calculation
1.1 Introduction

Heat loss primarily occurs when there is a difference in temperature between two adjoining areas or surfaces. The rate and scale of the heat lost will be determined by a number of variable factors. This unit will identify those factors and consider the methods used for calculation of U-values for different building fabric elements commonly found in Dwellings.

While there are many software packages available for calculating U-values, it is important to have an understanding of the fundamentals in relation to how the calculations are derived. This understanding will allow you to use U-value calculation software correctly, help you identify obvious errors in results and highlight the relationship between thermal conductivity, thermal resistance and how they impact on achieving desired U-values in building fabric.

At the end of this section you will be able to:

1. Outline the methods for calculating the energy performance of the external fabric of a dwelling as described in the current Building Regulations.
2. Calculate the U-value for simple constructions without thermal bridging.
3. Describe why constructions with repeated thermal bridging in their layers require a different approach to calculation
4. Discuss the implications of revised building standards on skills for construction workers

See links below to videos illustrating heat loss principles and calculations:

https://www.youtube.com/watch?v=DtTAWK9WBAM
https://www.youtube.com/channel/UCuVWfKPqDF9t1aSvcGkM0wQ
https://www.youtube.com/watch?v=jok1QbzAvJo
1.2 Measuring Heat Loss

Calculation methods for the determination of U-values of building elements are based on standards that were developed in the European Committee for Standardisation (CEN) and the International Organisation for Standardisation (ISO). These methods are appropriate for demonstrating compliance with building regulations for the conservation for fuel and energy, namely Part L of the Building Regulations.

While there are many U-value calculator software packages available on the market, it is important to have an understanding of the fundamentals of how the calculations are derived. This will help you to use U-value calculators correctly and allow you to identify obvious errors in results. It will also improve your understanding of the relationship between thermal conductivity, thermal resistance and how the air permeability level impacts on a building's overall fabric heat losses.

BUILDING FABRIC - Technical Guidance Document Part L

1.3.1.1 This section gives guidance on acceptable levels of provision to ensure that heat loss through the fabric of a dwelling is limited insofar as reasonably practicable.

Guidance is given on three main issues:

- Insulation levels to be achieved by the plane fabric elements (sub-section 1.3.2);
- Thermal bridging (sub-section 1.3.3);
- Limitation of air permeability (sub-section 1.3.4).

Heat losses from buildings can be categorised into two distinct areas:

- **Fabric heat losses** - conduction of heat through the various elements of the building fabric.
- **Ventilation/Infiltration heat losses** - when cold outside air replaces the heated indoor air, by a mixture of designed ventilation and undesired air infiltration.

**Fabric Heat losses**

The laws of thermodynamics state that heat flows naturally from warmer spaces to adjacent colder spaces. Heat transfer through the fabric of the building will occur through convection, conduction and/or radiation. The main factors which affect the scale and rate of heat loss are:
• **Temperature differences** between inside and outside - The greater the temperature difference, the higher the rate of heat transfer between adjoining surfaces.

• **Surface area** of the building in contact with outside - Long narrow buildings will have a higher proportion of surfaces exposed to the outside than a square/circular building of the same floor area.

• **Thermal properties** and thickness of the building materials - Each of the materials used in the construction of the building will have different inherent thermal properties and also depending on their thickness, will provide different levels of resistance to the passage of heat from warmer to colder areas.

The fabric loss can occur through the “plane areas”, i.e. the walls, roof, floor, and windows and doors or through the joints between the plane areas – the thermal bridges. The loss through the plane areas, which usually represents 80 – 90% of the total fabric loss, is quantified by the U-value of the components. Being able to determine which elements of the building contribute most to heat losses will inform decisions in relation to possible solutions. Heat losses occur mainly due to conduction, ventilation and air infiltration.

**Thermal Transmittance (U-Value)**

The thermal transmittance or U-value is the unit of measurement that describes how much heat is lost from a particular building material, such as a wall, window or roof. A low U-value means that the structure is good at retaining heat and a high U-value means that it loses a lot of heat. A wall with a U-value of 0.3 W/m²K loses heat at half the rate of a wall with a U-value of 0.6 W/m²K.

U-values are expressed in watts per metre squared Kelvin, W/m²K. It measures the amount of energy in Watts (W) that travels through each square metre of the structure (m²) per every 1 degree Kelvin of temperature difference between inside and outside (K).

The standard scientific unit of temperature is the Kelvin, which is represented by the symbol "K". The Kelvin scale has a different starting point to that used by the Celsius
temperature scale, so a temperature of 1K is not the same temperature as 1°C. The scales are, however, calibrated so that a temperature difference of 1K is the same as a temperature difference of 1°C. (Figure 2.2)

![Temperature scales diagram](image)

**Figure 2.2: temperature scales**

Using building components with low U-values has a number of advantages: A house built with low U-value building components will use less energy and thus save money on energy bills. Good U-value building components increase the surface temperature on the inside which is critical in preventing surface mould growth. Good U-values also improve the indoor thermal climate and create healthy buildings for their residents.

Building fabric heat losses are calculated with reference to temperature differences between one side of a construction and the other. When internal and external temperatures expressed are in °C, the temperature difference across the construction will have the same value whether expressed in °C or K.

U-values can apply to a single building material or a composite of building elements so knowledge of how to calculate U values during the design process avoids expensive re-working later on and allows the designer to test the performance and feasibility of the construction details to ensure it will comply with part L building standards.
The plane fabric heat loss for a building is determined by adding up all the calculated losses from the walls, roof, floor, windows and doors. Heat loss is calculated in Watts (W) by:

\[
\text{Heat Loss} = U \times A \times dT
\]

**Heat Loss** Watts (W)  
**U** = U-Value (W/m²K)  
**A** = Area of surface (m²)  
**dT** = Air temperature difference between inside/outside (K) or (°C)

The area where designers can exert the most influence in relation to the rate of heat loss is to the U-value attributed to each of the construction elements that make up the building. Choosing materials which will provide greater resistance to the passage of heat will result in construction details which facilitate lower U – values.

Consider the examples below which highlight the relationship between U-values, surface area and temperature difference in calculating overall heat loss.

**Example 1: Calculate the heat loss for the element detail shown.**

U-Value = 0.18W/m²K

\[
\text{Heat Loss} = U \times A \times dT
\]

\[
U : \text{U-Value} = 0.18W/m²K
\]

\[
A : \text{Area of surface} = 1m \times 1m = 1m²
\]

\[
dT : \text{Air temperature difference} = 1K
\]

\[
\text{Heat Loss} = 0.18 \times (1 \times 1) \times (18 - 17)
\]

\[
\text{Heat Loss} = 0.18 \times 1 \times 1
\]

**Heat Loss = 0.18W**
Example 2: Calculate the heat loss for the element detail shown.

U-Value = 0.18W/m²K

\[ \text{Heat Loss} = \text{Watts (W)} \]

\[
U \quad \text{- U-Value} = 0.18 \text{W/m}^2\text{K} \\
A \quad \text{- Area of surface} = 1\text{m} \times 1\text{m} = 1\text{m}^2 \\
dT \quad \text{- Air temperature difference} = 1\text{K} \\
\]

\[ \text{Heat Loss} = 0.18 \times (3x4) \times (18 - 10) \]

\[ \text{Heat Loss} = 0.18 \times 12 \times 8 \]

\[ \text{Heat Loss} = 17.28 \text{W} \]

The Building Regulations technical guidance part L set out the maximum elemental U-values that are permissible in the construction of new buildings and certain retrofitting scenarios. The maximum values depend on a number of factors including the size of the building, ratio of glazing and the building’s intended use.

In order to limit heat loss through the building fabric reasonable provision should be made to limit transmission heat loss by plane elements of the building fabric. Acceptable levels of thermal insulation for each of the plane elements of the building to achieve this are specified in terms of average area-weighted U-value (Um) in Table 1 – Technical Guidance Documents Part L 2011

Building regulations have changed over the years and now require higher levels of thermal insulation than ever before. To remain compliant, typical construction details have also improved in this regard. (Figure 2.3)
To calculate heat loss, the overall U-Value for the structure must be known. As the constituent parts of the structure will be different and contribute to heat loss at different rates, (Figure 2.4), designers must be able to calculate the different U-values through each of the structural elements, - floors, walls, roofs or windows and doors.

To calculate U-Values – “Thermal transmittance”, it is important to first understand the other terms used in the calculations, namely “Thermal Conductivity” and “Thermal Resistance”.

### Thermal Conductivity

Thermal conductivity is the property of a material which denotes how well it allows heat to flow. The thermal conductivity (known both as Lambda (λ) value or K-Value) is denoted using a number which measures the amount of heat that is transmitted through a specific material and is measured in watts per metre for a temperature gradient of one Kelvin per metre thickness - W/mK.

The thermal conductivity value (Lambda λ) attributed to a material relates to its inherent ability to conduct heat, i.e. the lower the λ-value, the better the thermal efficiency of the material. The table below lists the λ-values attributed to some of the more common building materials. The thermal conductivity of a material will not differ...
with dimensions but is dependent on its inherent properties of temperature, density and moisture content.

Information in relation to the thermal conductivity for building materials can be found from manufacturers information data sheets, Metric Handbook and the Architects’ Pocket Guide as well as a comprehensive listing by the International Organization for Standardisation - *ISO 10456 – 2007*.

**Table 2.1: Thermal conductivity values for common building materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>401</td>
</tr>
<tr>
<td>Aluminium</td>
<td>205</td>
</tr>
<tr>
<td>Cement Mortar</td>
<td>1.73</td>
</tr>
<tr>
<td>Concrete Block (H)</td>
<td>1.33</td>
</tr>
<tr>
<td>Glass Window</td>
<td>0.96</td>
</tr>
<tr>
<td>Clay Brickwork</td>
<td>0.77</td>
</tr>
<tr>
<td>Water</td>
<td>0.56</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.25</td>
</tr>
<tr>
<td>Cardboard</td>
<td>0.21</td>
</tr>
<tr>
<td>Concrete Block (L)</td>
<td>0.18</td>
</tr>
<tr>
<td>Softwood/plywood</td>
<td>0.13</td>
</tr>
<tr>
<td>Paper</td>
<td>0.05</td>
</tr>
<tr>
<td>Fibreglass/glass wool</td>
<td>0.04</td>
</tr>
<tr>
<td>Corkboard</td>
<td>0.043</td>
</tr>
<tr>
<td>Polystyrene / Styrofoam</td>
<td>0.033</td>
</tr>
<tr>
<td>Air at 0° C</td>
<td>0.024</td>
</tr>
<tr>
<td>PIR Board</td>
<td>0.022</td>
</tr>
<tr>
<td>Vacuum</td>
<td>0</td>
</tr>
</tbody>
</table>

Generally lighter (air-filled) materials and gases tend to have very low thermal conductivity properties and as such are considered very good insulators whereas metals tend to have really high thermal conductivity properties and as a result, are more effective conductors.
The thermal conductivity of water is higher than that of air so if insulating materials become wet and the air enclosures fill with water, the conductivity of the material increases. For this reason it is important to ensure insulation materials remain dry throughout construction.

**Thermal Resistance - R-Value**

Thermal resistance is a measure of a material's ability to resist heat transfer. The more a material is able to impede heat transfer through its surface, the greater its thermal resistance value. Thermal resistance is measured in m²K/W and is expressed as the thickness of the material (in metres) divided by its λ-value.

The resistances for each of the materials within an element are calculated and added together to determine the total resistance (RT) of the building element. The higher the R-value of a material, the better able it is to resist heat transfer. The lower the R-value, the easier it is for heat to pass through the material's surface.

Surfaces and cavities also provide a specific level of thermal resistance. Standardised values are specified for these resistances and must also be taken into account when calculating overall U-values.

\[
R = \frac{d}{K} \quad \text{or} \quad R = \frac{d}{\lambda}
\]

\[
R = \text{Thermal Resistance (m}^2\text{K/W)}
\]

\[
K \text{ or } \lambda = \text{Thermal Conductivity - K or Lambda value (W/mK)}
\]

\[
d = \text{Thickness of material (m)}
\]

\[
R_T = R_1 + R_2 + R_3 + R_4 + R_5
\]

\[
R_T = \text{Total Resistance}
\]
Example

Calculate the thermal resistance for 100mm thick PIR Board with a thermal conductivity value of 0.022 W/mK.

\[
R = \frac{d}{K} \quad \text{or} \quad R = \frac{d}{\lambda}
\]

\[ R = \text{Thermal Resistance m}^2\text{K/W} \]

\[ K \text{ or } \lambda = 0.022\text{W/mK} \]

\[ d = 100\text{mm} = 0.1\text{m} \]

\[
R = \frac{0.1}{0.022} = 4.53\text{ W/m}^2\text{K}
\]

Table 2.2 provides an overview of thermal transmittance (U-value), thermal conductivity and thermal resistance including symbols, units of measurement and formulae.

**Table 2.2: Summary of U-value, thermal conductivity and thermal resistance**

<table>
<thead>
<tr>
<th>Term</th>
<th>Symbol</th>
<th>Description</th>
<th>Formulae</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Transmittance</td>
<td>U</td>
<td>A measure of how much heat is lost through a material/structure</td>
<td>[Heat Loss = U \times A \times dT] [U = \frac{1}{R_T}]</td>
<td>W/m²K</td>
</tr>
<tr>
<td>U - Value</td>
<td>K</td>
<td>A measure of the inherent ability of a material to conduct heat.</td>
<td>Value is determined by testing in laboratory conditions and specified by the manufacturer as part of the product declarations</td>
<td>W/mK</td>
</tr>
<tr>
<td></td>
<td>\lambda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K - Value</td>
<td>\lambda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>\lambda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Resistance</td>
<td>R</td>
<td>A measure of the inherent ability of a material to resist heat transfer.</td>
<td>[R = \frac{d}{K} \quad \text{or} \quad R = \frac{d}{\lambda}] [R_T = R_1 + R_2 + R_3 + R_4]</td>
<td>m²K/W</td>
</tr>
<tr>
<td>R - Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Useful Link:

https://www.youtube.com/watch?v=fXjzqbRdR8g&list=PLYHHAmVjwQic792ajYz18354JKm6MlC-
**Surface Air Film Resistance**

Surface air film resistance results from convection currents at the surface of a material. It is a film of air which adheres to the surface by friction. It affects the temperature of the air immediately adjacent to the surface and since air is a good insulator, this factor and has been determined to hold an insulation value and measured in m²K/W.

The surface resistance factor is a fixed value and must be allowed for when calculating the thermal resistance of the building section and is applied to both the internal (R_{si}) and outside (R_{so}) surfaces as well as any ventilated air cavities (R_{air}).

The value of the internal and external surface resistances will depend on whether the calculations are based on a vertical or horizontal construction details. Vertical surface resistance factors are applied to sloping details of 70° or greater, whereas horizontal surface resistance factors are used for sloping details less than 70°. (see Table 2.3)

**Table 2.3: Air Surface Resistance**

<table>
<thead>
<tr>
<th>Resistance (Heat Flow)</th>
<th>Wall m²K/W (Horizontal)</th>
<th>Roof m²K/W (Upwards)</th>
<th>Floor m²K/W (Downwards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_{si}</td>
<td>0.13</td>
<td>0.1</td>
<td>0.17</td>
</tr>
<tr>
<td>R_{so}</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>R_{air}</td>
<td></td>
<td>0.18</td>
<td></td>
</tr>
</tbody>
</table>

**1.3 Calculating U-Values**

The fabric of the buildings structure is usually composed of a number of different materials of various thicknesses and thermal conductivity values. While U-values of the building fabric could previously be calculated by assuming that an element was made up of a series of layers each with uniform thermal resistance, (simple U-Value calculations) it is now recognised that features such as mortar joints, timber studs wall ties and even fixings contribute significantly to heat loss.

More complex calculation methods (combined U-Value calculations) have been introduced to take account of these. It has also been recognised that the joints between the walls, roofs and floors of a building can add significantly to the fabric heat loss. For simple calculations, the materials can be considered to act “in-series” while for the more complex calculations, heat loss through materials will be combined and occur “in-parallel”.

Unit 2 section 1
Note: The calculation examples presented mainly reflect new build situations but same principles can be applied to retrofit applications.

In Series U-Value Calculations

When materials are placed in series, their thermal resistances are added for a given temperature difference. An example of this would be a simple insulated cavity wall - all elements acting in series. The resistance to heat loss is uniform for the entire surface of the wall as the construction is identical. Heat flow through such uniform elements occurs in a straight line from inside to outside.

Figure 2.?: Heat flow path through wall construction (disregarding wall ties, fixings and mortar joints)

U-Value Calculations (In-series)

For simple U value calculations, the thermal resistance of each layer are calculated and added to surface resistance values for the building element to provide the total resistance.

\[ R = \frac{d}{K} \quad \text{or} \quad R = \frac{d}{\lambda} \]

\[ R_T = R_{si} + R_1 + R_2 + R_3 + R_4 + R_{so} \]

The U value is defined as being the reciprocal of all the resistances of the materials/layers within in the building element.
Simple U-value calculations do not account for thermal bridging but thermal conductivity values may be used which can account for mechanical fixings, wall ties and/or air gaps.

For U-value calculations related to walls, the effect of wall ties can be neglected:

a) In an un-insulated cavity,

b) Between masonry leaf and timber studs.

c) If the thermal conductivity of the tie is less than 1 W/mK, (i.e. plastic wall ties)

d) Where the adjustment in the U-value is less than 3% of the original value

In all other situations, the effect of wall ties needs to be considered in the overall calculation.

To calculate the U value of a building element such as a wall, floor or roof, the orientation and detail composition of the build-up of the element is required. Each building material should be positioned and listed in sequence and the thermal conductivity, thickness and surface resistance value of each building material/layer recorded. U values resulting from calculations should be rounded to 2 decimal places.

**In Parallel U-Value Calculations**

As practically all building elements are constructed in a non-uniform way (i.e. Mortar joints within masonry wall, timber joists with insulation infill, glazing within a timber frame) heat loss will not occur at the same rate through each material. Due to the different thermal properties, heat loss may be accelerated through paths offering lower levels of thermal resistances. In this instance, heat loss will occur in parallel though a number of different paths at different rates – Thermal bridging (see Figure 2.4).
Figure 2.4: Illustration of two possible heat loss pathways in timber wall construction

There may be one or more building elements in a typical dwelling construction that have layers which are repeatedly thermally bridged. Typical examples would be:

- A masonry cavity wall constructed with stainless steel or galvanised steel cavity ties
- A timber frame wall where the insulation layer is fitted between timber studs
- A wall dry-lined using battens with insulation fitted between
- A roof insulated at ceiling level with insulation fitted between ceiling joists
- A suspended timber floor insulated between the floor joists

When heat loss occurs in parallel within an element, the materials used may have vastly different thermal properties. In using the example of timber frame construction, the resistance to the passage of heat will vary at different locations taken through the construction detail, either through the stud and wall-ties or through the insulation and
cavity (see Figure 2.5). Heat loss calculations must account for the proportionally different thermal resistances throughout the structural element due to thermal bridging.

Figure 2.5: Heat loss pathways in parallel

The total resistance of the overall building element (wall, floor, roof etc.) includes all of the resistances for each of the individual materials used in the construction as well as both the internal and external surface air-film resistance.

In-parallel U-Value calculations account for the different rates of heat loss through the heat loss paths at both the upper and lower limits of the building detail. This accounts for the proportionally different cross sectional details over the wall area as well as discrepancies where different materials meet.

The upper level of resistance \( R_U \) can be described as the resistance offered in the best case scenario which assumes that heat flows in straight lines perpendicular to the wall surface.

The resistances for each pathway are calculated resulting in an overall upper resistance \( R_U \) based on their % area within the structure.

The lower level of resistance \( R_L \) can be described as the resistance offered in the worst case scenario where proportionally more heat is lost through the pathways offering lower levels of resistance.

The resistance offered by the thermal bridge \( R_B \) is calculated using the combined heat loss rates for each material based on their thermal conductivity \( (\lambda) \) and proportional area.

The combined thermally bridged value is then used to establish the lower level of resistance \( R_L \).
The overall resistance is then determined from the average of both the upper and lower levels of resistance \( R_t = \frac{R_u + R_l}{2} \) and used to calculate the overall U-value \( U = \frac{1}{R_t} \).

As insulation values of new buildings improve, the need to limit heat loss through thermal bridging becomes increasingly important. Poor detailing at design stage or sub-standard construction work can have a significant adverse effect on building performance.

The insulation envelope of any heated building should be designed and constructed to limit heat loss through thermal bridging at both

(a) Repeating thermal bridging within building elements
(b) Non-repeating thermal bridging at the junction between building elements

Heat loss associated with thermal bridges is taken into account in calculating energy use and CO\(_2\) emissions using the DEAP methodology.
1.4 Building Element U-Values for Walls

In the calculation of U-values for building elements, the thermal resistance for each component within the element is first calculated. These thermal resistances along with the appropriate surface resistances are combined to yield the total thermal resistance, the reciprocal of which provides the elemental U-value.

The maximum area weighted elemental U-value permitted for a wall adjoining unheated spaces is 0.21W/m²K. As walls tend to be constructed using a number of different materials within the element, heat loss may not occur uniformly over the whole area. The example calculations below examine situations where heat loss does occur uniformly (in series) and more commonly, where heat loss occurs at different rates through different pathways (in-parallel)

Example 1: In-series U-value calculation

Calculate the U value (Thermal Transmittance) for the building element detailed below in Figure 2.6.

![Diagram A1: Masonry cavity wall (Par. A2.1)](image)

The thickness and thermal conductivity for each material is indicated and the inside and outside surface resistance factors for horizontal heat flow through a wall can be used from Table 2.4 (values from ISO 9646).

Figure 2.6: Section through masonry cavity wall (source: TGD Part L 2011)

The thickness and thermal conductivity for each material is indicated and the inside and outside surface resistance factors for horizontal heat flow through a wall can be used from Table 2.4 (values from ISO 9646).
Table 2.4: Air Surface Resistance

<table>
<thead>
<tr>
<th>Resistance (Heat Flow)</th>
<th>Wall m²K/W (Horizontal)</th>
<th>Roof m²K/W (Upwards)</th>
<th>Floor m²K/W (Downwards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{si}$</td>
<td>0.13</td>
<td>0.1</td>
<td>0.17</td>
</tr>
<tr>
<td>$R_{so}$</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>$R_{air}$</td>
<td></td>
<td></td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 2.5: Calculating total thermal resistance (In-series)

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thickness /m</th>
<th>Conductivity W/mK</th>
<th>Thermal Resistance m²k/W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d$</td>
<td>$K$ or $\lambda$</td>
<td>$R = \frac{d}{\lambda}$</td>
</tr>
<tr>
<td>Internal Surface $R_{si}$</td>
<td>0.13</td>
<td>0.180</td>
<td>0.1300</td>
</tr>
<tr>
<td>Lightweight Plaster</td>
<td>0.100</td>
<td>1.330</td>
<td>0.0752</td>
</tr>
<tr>
<td>Concrete Block</td>
<td>0.100</td>
<td>1.000</td>
<td>0.0190</td>
</tr>
<tr>
<td>Thermal Insulation</td>
<td>0.100</td>
<td>0.023</td>
<td>4.3478</td>
</tr>
<tr>
<td>Unvented Air Cavity $R_{air}$</td>
<td>0.100</td>
<td>1.330</td>
<td>0.0752</td>
</tr>
<tr>
<td>External Render</td>
<td>0.019</td>
<td>1.000</td>
<td>0.0400</td>
</tr>
<tr>
<td>Internal Surface $R_{so}$</td>
<td>0.0400</td>
<td>1.000</td>
<td>0.0400</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td></td>
<td></td>
<td><strong>4.939 m²k/W</strong></td>
</tr>
</tbody>
</table>

**Step 1:** List materials & calculate each element thermal resistance based on thickness and thermal conductivity.

\[
R = \frac{d}{\lambda}
\]

**Step 2:** Add all the element resistance values to determine the total resistance. (Table 5)

**Step 3:** The U-value is calculated from the reciprocal of the combined thermal resistances of the materials in the element. This includes all the different materials, air spaces, surface resistance and would normally take into account the effect of thermal bridges and fixings.

Using $U = \frac{1}{R_T}$ calculate the U value for the building element detail.
\[ U = \frac{1}{4.939} \quad U = 0.203 \text{W/m}^2\text{K} \]

Note:

- Maximum permitted elemental U-value for walls = 0.21W/mm²K
- This calculation does not account for wall ties & mortar joints

**Example 2: In Parallel U-value calculation**

*Calculate the U value (Thermal Transmittance) for the building element detailed below in Figure 2.7.*

---

**Figure 2.7: Section trough timber frame wall construction (source: TGD Part L 2011)**

The thickness and thermal conductivity for each material is indicated and the inside and outside surface resistance factors for horizontal heat flow through a wall can be used from Table 2.? above or values from ISO 9646 Table 1 and Table 2.

In this example, heat can flow can be measured through a number of paths across the construction element shown above (see Figure 2.8).

1. Through the stud
2. Through the insulation
3. Through the thermally bridged elements.
**U-value calculations for thermally bridged elements**

<table>
<thead>
<tr>
<th>Step</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculate the thermal resistance for each heat loss path.</td>
</tr>
<tr>
<td>2</td>
<td>Calculate the upper resistance value, R-Upper $R_U$</td>
</tr>
<tr>
<td>3</td>
<td>Calculate the thermal resistance for the bridged layer, R-Bridged $R_b$</td>
</tr>
<tr>
<td>4</td>
<td>Calculate the lower resistance value, R-Lower $R_L$</td>
</tr>
<tr>
<td>5</td>
<td>Calculate the total elemental thermal resistance value using $R_U$ and $R_L$</td>
</tr>
<tr>
<td>6</td>
<td>Calculate the U-value for the element</td>
</tr>
</tbody>
</table>

Figure 2.8: Three heat loss pathways through timber frame construction
STEP 1: Calculating Thermal resistance for heat flow paths

List materials & calculate each element thermal resistance based on thickness and thermal conductivity for each heat loss path through both the stud (1) and the insulation (2). Adding all the element resistance values will determine the total resistance for each heat flow path see Table 2.5 And 2.6.

Table 2.5: Thermal resistance through path 1 - Timber stud

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thickness /m</th>
<th>Conductivity W/mK</th>
<th>Thermal Resistance m²k/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface $R_p$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.013</td>
<td>0.250</td>
<td>0.0520</td>
</tr>
<tr>
<td>Timber Stud</td>
<td>0.150</td>
<td>0.120</td>
<td>1.2500</td>
</tr>
<tr>
<td>Ply Sheeting</td>
<td>0.012</td>
<td>0.130</td>
<td>0.0923</td>
</tr>
<tr>
<td>Unvented Air Cavity $R_{air}$</td>
<td></td>
<td></td>
<td>0.1800</td>
</tr>
<tr>
<td>External Brick</td>
<td>0.102</td>
<td>0.770</td>
<td>0.1325</td>
</tr>
<tr>
<td>External Surface $R_{sp}$</td>
<td></td>
<td></td>
<td>0.0400</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td></td>
<td></td>
<td><strong>1.877</strong></td>
</tr>
</tbody>
</table>

Table 2.6: Thermal resistance through path 2 - Insulation

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thickness /m</th>
<th>Conductivity W/mK</th>
<th>Thermal Resistance m²k/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface $R_i$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.013</td>
<td>0.250</td>
<td>0.0520</td>
</tr>
<tr>
<td>Thermal Insulation</td>
<td>0.150</td>
<td>0.023</td>
<td>6.5217</td>
</tr>
<tr>
<td>Ply Sheeting</td>
<td>0.012</td>
<td>0.130</td>
<td>0.0923</td>
</tr>
<tr>
<td>Unvented Air Cavity $R_{ai}$</td>
<td></td>
<td></td>
<td>0.1800</td>
</tr>
<tr>
<td>External Brick</td>
<td>0.102</td>
<td>0.770</td>
<td>0.1325</td>
</tr>
<tr>
<td>External Surface $R_{ip}$</td>
<td></td>
<td></td>
<td>0.0400</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td></td>
<td></td>
<td><strong>7.149</strong></td>
</tr>
</tbody>
</table>
The timber stud and insulation provide hugely different levels of resistance to the passage of heat and the proportional area of each is also hugely different within the building element. The different proportional areas must be factored into calculations and rate of heat loss through both elements is combined to establish the Upper thermal resistance $R_U$.

The overall U-value calculation for in-parallel elements must allow for the different rates of heat loss both at the upper and lower levels of thermal resistance $R_U$ and $R_L$ as well as through the bridged element $R_b$. The timber stud framework is effectively creating a repeated thermal bridge in the wall construction. The area occupied by the bridged element (stud) is expressed as a percentage/fraction of the overall construction element as calculations are based on the fractional areas of heat flow paths. For timber frame walls, this represents 15%. This is calculated based on the size and spacing of timberwork within the wall structure.

Where the size and frequency of timber framework is unknown, values for different building element scenarios are provided in TGD L 2011 (see Figure 2.9)

![Figure 2.9: Timber fractions for bridged layers (source: TGD L 2011)](image)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Timber frame walls</th>
<th>Ceiling flat/sloped</th>
<th>Dry lined battened wall</th>
<th>Suspended timber floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Fraction</td>
<td>15</td>
<td>9</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>
STEP 2: Calculating $R_U$ – Upper ($R_U$)

For this element calculation, the timber stud ($F_{\text{tim}}$) represents an area of 15% while the insulation ($F_{\text{ins}}$) represents the remaining 85%.

The upper thermal resistance $R_U$ is calculated using these values along with their corresponding thermal resistance which has been calculated in step 2.

<table>
<thead>
<tr>
<th>Fractional Area ($F$)</th>
<th>Thermal resistance path ($R$)</th>
<th>$F \div R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tim Stud</td>
<td>0.15</td>
<td>1.877</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.85</td>
<td>7.149</td>
</tr>
<tr>
<td>Total Resistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_U$</td>
<td>$\frac{1}{R_T}$</td>
<td>5.03 m²K/W</td>
</tr>
</tbody>
</table>

\[
R_U = \frac{F_{\text{tim}}}{(F_{\text{tim}} + R_1 + F_{\text{ins}} + R_2)}
\]

\[
R_U = \frac{1}{(0.15 \div 1.877 + 0.85 \div 7.149)}
\]

$R_U = 5.03 \text{ m}^2\text{K/W}$
STEP 3: Calculating R – Bridged (R_b)

To calculate the lower thermal resistance $R_L$, the thermal resistance of the bridged layer $R_b$, must be first calculated. This is based on each materials thermal resistance accounting for fractional areas.

$$\frac{1}{R_b} = \frac{1}{R_T} = \frac{F_{tim}}{R_{tim}} + \frac{F_{ins}}{R_{ins}}$$

$$R_b = \frac{1}{0.2503} = 3.995m^2K/W$$

**R_b Bridged Thermal Resistance**

<table>
<thead>
<tr>
<th>Fractional Area (F)</th>
<th>Thermal resistance (R)</th>
<th>F×R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tim Stud</td>
<td>0.15</td>
<td>1.25</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.85</td>
<td>6.5217</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td><strong>0.2503</strong></td>
<td></td>
</tr>
<tr>
<td>$R_b$</td>
<td>$\frac{1}{R_T}$</td>
<td><strong>3.995m^2K/W</strong></td>
</tr>
</tbody>
</table>

$$R_b = \frac{1}{(0.15 \div 1.25 + 0.85 \div 6.5217)}$$
STEP 4: Calculating R –Lower (R_L)

To calculate the Lower thermal resistance \( R_L \), the thermal resistance of all layers which includes the bridged element are combined in series to give the lower resistance.

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thermal resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface ( R_{si} )</td>
<td>0.130</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.052</td>
</tr>
<tr>
<td>Bridged Layer ( R_b )</td>
<td>3.995</td>
</tr>
<tr>
<td>Ply Sheeting</td>
<td>0.092</td>
</tr>
<tr>
<td>Unvented Air Cavity ( R_{air} )</td>
<td>0.180</td>
</tr>
<tr>
<td>External Brick</td>
<td>0.132</td>
</tr>
<tr>
<td>External Surface ( R_{so} )</td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Lower Resistance ( R_L )</strong></td>
<td><strong>4.622 m²k/W</strong></td>
</tr>
</tbody>
</table>

STEP 5: Calculating R–Total (R_t)

The total elemental thermal resistance can now be calculated as it is the average of the upper \( R_U \) and lower \( R_L \) thermal resistance:

\[
R_t = \frac{R_U + R_L}{2}
\]

\[
R_t = \frac{5.03 + 4.622}{2} = 4.826
\]

STEP 6: Calculating Element U-Value (U)

Using \( U = \frac{1}{R_t} \) calculate the U value for the building element detail.

\[
U = \frac{1}{R_t} = \frac{1}{4.826} = 0.207 \text{ W/m}^2\text{K}
\]
NOTE:

The effect of wall ties needs to be considered in cavity wall construction. Heat loss calculations are based on the thermal conductivity and the cross-sectional area of the tie as well as the number of ties per m².

The effect of wall ties can be neglected in situations where

- The cavity is un-insulated
- The wall-tie is between a timber leaf and a masonry leaf
- The normal conductivity of the tie is less than 1 W/m²K
- The adjustment in U-value is less than 3%

If plastic wall ties are used, heat loss rates are negligible as the conductivity rates are less than 1 W/m²K and as such can be disregarded in calculations.

1.5 Building Element U-Values for Floors

Calculating the heat loss through floors involves a number of specific localised factors. Soil has a high inherent specific heat and the value of different soils can vary considerably between regions resulting in considerably different rates of heat loss. The rate of heat loss is not only affected by the density of the soil but also the amount of water present. Unlike heat loss through elements above ground, this results in different rates of heat loss over the area of the floor.

The ground under the middle of a slab stays at a nearly constant temperature all year, while the ground near the outer edge changes seasonally with air/ground temperature variances. This would indicate why in earlier TGD’s, insulation was only placed beneath the perimeter of the floor to address heat loss in the area of greatest temperature difference.

Un-insulated ground floors

BRE Information Paper IP 3/90 outlines simplified formulas that can be used for all types of un-insulated ground floor including;

- Ground bearing
- Suspended concrete
- Suspended timber.
It can be used with relative ease for basic rectangular shaped floors as well as complex and irregularly shaped floor plans. The formula which is based on the relationship between the floor area and the length of exposed perimeter is defined using the values below.

\[
U_{FLOOR} = 0.05 + 1.65PA - 0.6PA^2
\]

- \(U\) = U-Value of the un-insulated floor (W/m²K).
- \(P\) = Length of the exposed perimeter (m).
- \(A\) = Area of the floor (m²)

The measurement of the perimeter and the area should be based on the inside surface of the internal perimeter walls that enclose the heated space. Unheated spaces such as garages and porches should be excluded. The perimeter should not include walls between adjacent heated areas such as semi-detached or terraced properties.

**Example 1:** Calculate the U-value for the un-insulated concrete ground floor for the building shown below in Figure 2.10.

![Figure 2.10: Plan of un-insulated concrete floor](image)
\[ U_{FLOOR} = 0.05 + 1.65P/A - 0.6(P/A)^2 \]

\[ U = U\text{-Value of the un-insulated floor (W/m}^2\text{K)}. \]

\[ P = \text{Length of the exposed perimeter} = (6 - 0.6) + (10 - 0.6) + (6 - 0.6) = 20.2\text{m}. \]

\[ A = \text{Area of the floor} = 5.4 \times 9.4 = 50.76\text{m}^2 \]

\[ U_{FLOOR} = 0.05 + 1.65(20.2 \div 50.76) - 0.6(20.2 \div 50.76)^2 \]

\[ U_{FLOOR} = 0.05 + 1.65(0.398) - 0.6(0.158) \]

\[ U_{FLOOR} = 0.05 + 0.657 - 0.095 \]

\[ U_{FLOOR} = 0.612\text{W/m}^2\text{K} \]

**Insulated ground floors**

I.S EN ISO 13370;2007 outlines the following formulae for calculating the u-values for well insulated floors.

\[ U_{FLOOR} = \frac{\lambda_g}{(0.457B' + d_t)} \]

For this calculation, the characteristic dimension of the floor \( B' \) and equivalent thickness value \( d_t \) are required.

\[ U = U\text{-Value of the well-insulated floor (W/m}^2\text{K)}. \]

\[ \lambda_g = \text{Thermal conductivity of unfrozen ground (W/mK) The ISO standard 13370: Table 1 states that this has a set value of 2W/mK unless otherwise known.} \]

\[ B' = \text{Characteristic dimension of the floor (m), for insulated floors: } B' = \frac{2A}{P} \]

\[ A = \text{Area of the floor (m}^2\text{)} \]

\[ P = \text{Heat loss perimeter (m)} \]

\[ d_t = \text{Equivalent thickness (m)} \]

\[ d_t = w + \lambda_g(R_{si} + R_f + R_{se}) \]

\[ w = \text{Wall thickness (m)} \]

\[ \lambda_g = \text{Thermal conductivity of unfrozen ground} = 2\text{W/mK} \]

\[ R_{si} = \text{Internal Surface resistance for floor} = 0.17\text{m}^2\text{K/W} \]

\[ R_{se} = \text{External Surface resistance for floor} = 0.04\text{m}^2\text{K/W} \]

\[ R_f = \text{Floor fabric resistance (m}^2\text{K/W)} \]
The internal and external surface resistance $R_{SI}$ and $R_{SE}$ required in the calculation of the equivalent thickness $d_i$ has a set value for floors as indicated in Table 2.4 previously.

The ISO standard also states that the thermal resistance of dense concrete slabs and thin floor coverings may be ignored in the calculation. Hardcode filling below the slab is assumed to have the same thermal conductivity as the ground and can also be ignored.

Edge insulation is seen to contribute to preventing thermal bridging and is not considered to contribute to the thermal insulation of the floor unless it extends below the external ground level.

**Example 2:** Calculate the U-value for the insulated concrete ground floor for the building shown in Figure 2.11. The floor is evenly insulated with 100mm of insulation with $\lambda = 0.023\text{W/mK}$

**Figure 2.11: Plan of insulated concrete floor with section showing perimeter insulation**

**Step 1:** Calculate the characteristic dimension of the floor $B'$ using area ($A$) and perimeter ($P$)

$$B' = \frac{2A}{P}$$

$P =$ Length of the exposed perimeter $= (6 - 0.6) + (10 – 0.6) + (6 – 0.6) = 20.2\text{m}$.

$A =$ Area of the floor $= 5.4 \times 9.4 = 50.76\text{m}^2$

$$B' = \frac{2A}{P} = \frac{2(50.76)}{20.2} = 5.026$$
**Step 2:** Calculate the equivalent thickness $d_t$ using

$$d_t = w + \lambda_g (R_{si} + R_f + R_{se})$$

$w =$ Wall thickness $= 0.3m$

$\lambda_g =$ Thermal conductivity of unfrozen ground $= 2W/mK$ (EN ISO 13370)

$R_{si} =$ Internal Surface resistance for floor $= 0.17m^2K/W$ (EN ISO 6946)

$R_{se} =$ External Surface resistance for floor $= 0.04m^2K/W$ (EN ISO 6946)

$R_F =$ Floor fabric resistance

$$d_t = w + \lambda_g (R_{si} + R_f + R_{se})$$

$$d_t = 0.3 + 2(0.17 + 4.348 + 0.04)$$

$$d_t = 0.3 + 2(0.17 + 4.348 + 0.04)$$

$$d_t = 9.416m$$

**Step 3:** Calculate $u$ value using

$$U_{FLOOR} = \frac{\lambda}{(0.457B' + d_t)}$$

$\lambda_g =$ Thermal conductivity of unfrozen ground $= = 2W/mK$ (EN ISO 13370)

$B' =$ Characteristic dimension of the floor $= 5.026$

$d_t =$ Equivalent thickness $= 9.416$

$$U_{FLOOR} = \frac{\lambda}{(0.457B' + d_t)}$$

$$U_{FLOOR} = \frac{2}{(0.457 \times 5.026 + 9.416)}$$

$$U_{FLOOR} = 0.171W/m^2K$$
1.6 Building Element U-Values for Roofs

In the construction of roof structures, as with all other fabric constructions, the performance of the system is dependent on the control of air and moisture movement between the warm and cold sides of the insulation.

Roof structures can be classified as either cold or warm depending on the position of the insulation in relation to the structure as well as the amount of air circulation/ventilation provided.

In cold roofs (see examples in Figure 2.12), the insulation is installed below the roof structure and the outside air is allowed to freely circulate beneath the waterproof roof covering and also between the structural members - rafters.

![Figure 2.12: Cold Roof](image)

In warm roofs (see example in Figure 2.13), the insulation is typically installed above the roof structure just below the weatherproof sheeting and in this instance, the space under the insulation is closed to fresh air flow.

![Figure 2.13: Warm Roof](image)

When calculating elemental U-values for roofs, the U-value is calculated for the ceiling and not for the sloping roof. A thermal resistance value based on EN6946 for the ventilated roof space of $0.2 \text{m}^2 \text{k/W}$ is taken from TGD L (see Figure 2.14).
In the design of the roof, consideration must be given to:

- Provision of adequate ventilation
- Control of water vapour
- Minimising cold bridging
- Protecting water services/fittings from freezing
- Avoiding overheating of electrical services/fittings
- Access to services

**Example 1:**

**Calculate the U value (Thermal Transmittance) for the cold pitched roof detailed in Figure 2.15.**

The thickness and thermal conductivity for each material is indicated and the inside and outside surface resistance factors for upwards heat flow can be taken from Table 2.4 previously.
Figure 2.15: Pitched roof construction insulated at ceiling level

Due to the nature of the construction detail shown, heat will flow at different rates though the timber joist and through the insulation so heat loss must be measured through each of paths across the construction element. (In-Parallel)

The rate of heat loss will be greater across the ceiling joist (thermal bridging) due to its higher thermal conductivity value.

In this detail, a second layer of insulation is installed above the ceiling joist which reduces the level of thermal bridging that will occur but there is still a thermally bridged layer $R_b$.

### U-value calculations for thermally bridged elements

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Calculate the thermal resistance for each heat loss path.</td>
</tr>
<tr>
<td>Step 2</td>
<td>Calculate the upper resistance value, $R_{Upper}$ $R_U$</td>
</tr>
<tr>
<td>Step 3</td>
<td>Calculate the thermal resistance for the bridged layer, $R_{Bridged}$ $R_b$</td>
</tr>
<tr>
<td>Step 4</td>
<td>Calculate the lower resistance value, $R_{Lower}$ $R_L$</td>
</tr>
<tr>
<td>Step 5</td>
<td>Calculate the total elemental thermal resistance value using $R_U$ and $R_L$</td>
</tr>
<tr>
<td>Step 6</td>
<td>Calculate the U-value for the element</td>
</tr>
</tbody>
</table>
Step 1: List materials & calculate the overall thermal resistance for each heat loss path based on thickness and thermal conductivity of the materials.

\[ R = \frac{d}{\lambda} \]

### Thermal Resistance Path 1: Insulation

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thickness</th>
<th>Conductivity</th>
<th>Thermal Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface R_{si}</td>
<td></td>
<td></td>
<td>0.100</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.013</td>
<td>0.250</td>
<td>0.052</td>
</tr>
<tr>
<td>Insulation (Between)</td>
<td>0.100</td>
<td>0.040</td>
<td>2.500</td>
</tr>
<tr>
<td>Insulation (Above)</td>
<td>0.150</td>
<td>0.040</td>
<td>3.750</td>
</tr>
<tr>
<td>Ventilated Roof</td>
<td></td>
<td></td>
<td>0.200</td>
</tr>
<tr>
<td>Internal Surface R_{SE}</td>
<td></td>
<td></td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td>(F_{ins})</td>
<td></td>
<td>6.642 m²K/W</td>
</tr>
</tbody>
</table>

### Thermal Resistance Path 2: Ceiling Joist

<table>
<thead>
<tr>
<th>Material/Surface</th>
<th>Thickness</th>
<th>Conductivity</th>
<th>Thermal Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface R_{si}</td>
<td></td>
<td></td>
<td>0.100</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.013</td>
<td>0.250</td>
<td>0.052</td>
</tr>
<tr>
<td>Ceiling Joist</td>
<td>0.100</td>
<td>0.130</td>
<td>0.769</td>
</tr>
<tr>
<td>Insulation (Above)</td>
<td>0.150</td>
<td>0.040</td>
<td>3.750</td>
</tr>
<tr>
<td>Ventilated Roof</td>
<td></td>
<td></td>
<td>0.200</td>
</tr>
<tr>
<td>Internal Surface R_{SE}</td>
<td></td>
<td></td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td>(F_{tim})</td>
<td></td>
<td>4.911 m²K/W</td>
</tr>
</tbody>
</table>

The overall U-value calculation for in-parallel elements must allow for the different rates of heat loss both at the upper and lower levels of thermal resistance \( R_U \) and \( R_L \).

Step 2: Calculate the upper level of thermal resistance \( R_U \) based on the proportional area and overall thermal resistance of each heat flow path.

The rate of heat loss through both elements is combined to establish the Upper thermal resistance \( R_U \). As with the timber stud wall example earlier, the ceiling joists...
will provide hugely different levels of resistance to the passage of heat and the different proportional areas must also be factored into calculations. For flat ceilings, this represents 9% of the overall area. This is calculated based on the size and spacing of timberwork within the ceiling structure. TGD Part L states the typical fractional values bridged layers in walls ceilings and floors.

<table>
<thead>
<tr>
<th>Table A2</th>
<th>Timber fractions for bridged layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>Timber frame walls</td>
</tr>
<tr>
<td>% Fraction</td>
<td>15</td>
</tr>
</tbody>
</table>

Step 3: To calculate the lower thermal resistance $R_L$, the thermal resistance of the bridged layer $R_b$, must be first calculated. This is based on each material’s thermal resistance within the bridged portion of heat flow while accounting for related fractional areas.

$$R_U = \frac{1}{F_{tim} + F_R + F_{ins}}$$

$$R_U = \frac{1}{(0.09 + 4.911 + 0.91 + 6.642)}$$

$$R_U = 6.439m^2K/W$$

<table>
<thead>
<tr>
<th>$R_U$</th>
<th>Upper Thermal Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Flow Path</td>
<td>Fractional Area (F)</td>
</tr>
<tr>
<td>Ceiling Joist</td>
<td>0.09</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.91</td>
</tr>
<tr>
<td>Total Resistance</td>
<td>0.155</td>
</tr>
<tr>
<td>$R_U = \frac{1}{R_T}$</td>
<td>6.439m²K/W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$R_b$</th>
<th>Bridged Thermal Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractional Area (F)</td>
<td>Thermal resistance (R)</td>
</tr>
<tr>
<td>Ceiling Joist</td>
<td>0.09</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.91</td>
</tr>
<tr>
<td>Total Resistance</td>
<td>0.477</td>
</tr>
<tr>
<td>$R_b = \frac{1}{R_T}$</td>
<td>2.096m²K/W</td>
</tr>
</tbody>
</table>

Unit 2 section 1
Step 4: To calculate the Lower thermal resistance $R_L$, the thermal resistance of all layers which includes the bridged element are combined in series to give the lower resistance.

\[ R_b = \frac{1}{F_{tim} + R_{tim} + F_{ins} + R_{ins}} \]

\[ R_b = \frac{1}{0.09 + 0.796 + 0.91 + 2.5} \]

\[ R_b = 2.096 m^2K/W \]

Step 5: The total elemental thermal resistance can now be calculated as it is the average of the upper $R_U$ and lower $R_L$ thermal resistance:

\[ R_t = \frac{R_U + R_L}{2} \]

\[ R_t = \frac{6.439 + 6.238}{2} \]

\[ R_t = 6.338 \]

Step 6: Using \[ U = \frac{1}{R_t} \] calculate the U value for the building element detail.

\[ U = \frac{1}{6.338} \]

\[ U = 0.16 W/m^2K \]

1.7 Building Element U-Values for Windows & Doors

Windows and doors, even high energy performance rated products, have significantly higher U-values than those prescribed in current standards for roof, wall and floor elements in a dwelling. As a result, windows and doors contribute to higher levels of heat loss through the fabric of the building and their combined area will have a significant impact on the overall heat loss.
The current building regulations state the permitted U-values for windows and doors based on their combined area expressed as a percentage of the floor area.

The average area-weighted U-value of 1.6W/m$^2$K for windows and doors only applies when their combined area equates to 25% of the floor area (see Figure 2.16).

\[
\begin{array}{|c|c|c|}
\hline
\text{Column 1} & \text{Column 2} & \text{Column 3} \\
\text{Fabric Elements} & \text{Area-weighted Average Elemental U-Value (Um)} & \text{Average Elemental U-value – individual element or section of element} \\
\hline
\text{Roots} & 0.16 & 0.3 \\
- Insulation at ceiling & 0.16 & \\
- Insulation on slope & \\
\text{Flat roof} & 0.20 & \\
\text{Walls} & 0.21 & 0.6 \\
\text{Ground floors$^3$} & 0.21 & 0.6 \\
\text{Other exposed floors} & 0.21 & 0.6 \\
\text{External doors, windows and rooflights} & 1.6$^4$ & 3.0 \\
\hline
\end{array}
\]

Notes:
1. The U-value includes the effect of unheated voids or other spaces.
2. For alternative method of showing compliance see paragraph 1.3.2.3.
3. For insulation of ground floors and exposed floors incorporating underfloor heating, see paragraph 1.3.2.2.
4. Windows, doors and rooflights should have a maximum U-value of 1.6 W/m$^2$K when their combined area is 25% of floor area. However areas and U-values may be varied as set out in Table 2.

\[\text{Figure 2.16: Maximum elemental U-values TGD L 2011 Dwellings}\]

Permitted variations in the opening to floor-area ratios are outlined in Table 2 TGD Part L. Intermediate values can be allowed for by interpolation and values outside the range can be established by calculation (Figure 2.17).
1.8 Building Element U-Values for Unheated Spaces

The term unheated space is used to describe areas within the structural space of the dwelling that are

- Unheated
- Large enough to crawl in
- Located between a heated space and the external environment
- Ventilated using outside air.

Typical examples of these spaces include garages, pitched roof (cold construction) crawl spaces, apartment access corridors, stairwells, external store rooms and even some conservatories/sunrooms.
Unheated spaces can reduce the rate at which heat is lost to the external environments and in such cases are allocated the appropriate thermal resistance for unheated spaces \( R_u \).

Part L TGD’s tables A3-A5 specify values for typical effective thermal resistances for unheated spaces under particular circumstances (see Figure 2.18).

Figure 2.18: Table A3, Diagram A5 and Table A5 (source: TGD Part L 2011)

The elemental U-Value must account for the proximity of adjacent unheated spaces and is derived using the formulae below and as with all U-values, measured in W/m²K
**Example 1: Unheated spaces calculation**

Calculate the adjusted U value (Thermal Transmittance) for the wall adjacent to the unheated crawl space detailed below.

\[ U = \frac{1}{\frac{1}{U_o} + R_u} \]

- **\( U \):** Elemental U-value (W/m\(^2\)K)
- **\( U_o \):** Original U-value of element adjacent to unheated space (W/m\(^2\)K)
- **\( R_u \):** Effective thermal resistance of unheated space. (m\(^2\)K/W)

**\( U \):** Elemental U-value (W/m\(^2\)K)

**\( U_o \):** Original U-value of element adjacent to unheated space = 0.2 W/m\(^2\)K

**\( R_u \):** Effective thermal resistance of unheated space = 0.5 m\(^2\)K/W

\[ U = \frac{1}{\frac{1}{0.2} + 0.5} \]

\[ U = \frac{1}{5.5} \]

\[ U = 0.18 W/m^2 K \]

From this example, it can be seen that the U-value of the wall has been adjusted from 0.2 W/m\(^2\)K to 0.18 W/m\(^2\)K due to its proximity to an unheated space within the building structure.
1.9 Overall Heat Loss Calculation

Overall heat loss calculations must account for:

- **Fabric heat losses** - conduction of heat through the various elements of the building fabric – floors, walls, roof, windows and doors which includes:
  - Plane elements + repeated thermal bridges
  - Linear thermal bridges
- **Ventilation heat losses** - when cold outside air replaces the heated indoor air, by a mixture of designed ventilation and undersigned air infiltration.

Total heat loss can be determined by calculating the sum of all the losses through the fabric and all losses due to air infiltration (figure 2.19).

**Figure 2.19: Overall Heat Loss Calculation**

**Plane elements**

The overall heat loss though each plane element which includes repeated thermal bridging is expressed in watts (W) using

\[ \text{Plane element heat losses} = U \times A \times \Delta T \]

- **U**: U value Thermal transmittance (W/m²K)
- **A**: Surface area through which heat transfer occurs (m²)
- **ΔT**: Temperature difference between inside and outside. (°C or K)
Linear thermal bridging - $\Psi$

As part of the fabric heat loss calculations, losses due to thermal bridging must be accounted for. Thermal bridging in the plane elements (repeating thermal bridges) has been accounted for within the respective building element calculations but allowance for losses due to non-repeating thermal bridges – linear thermal bridges ($\Psi$), has not.

The transmission heat loss coefficient for non-repeating thermal bridges is calculated from

$$H_{TB} = (L \times \Psi) \, W/K$$

$H_{TB}$: Transmission heat loss coefficient.

$L$: Length of the thermal Bridge over which $\Psi$ applies.

$\Psi$: Linear thermal transmittance

Calculations related to $\Psi$ values require the use of numeric modelling software and for TGD part L outlines two alternative approaches for inputting $\Psi$ values when using DEAP.

1. Heat losses can be expressed as a fraction of the exposed surface area of the building. ($y$)
   a. Where ACD’s have been used: $y = 0.8$
   b. Where ACD’s have not been used: $y = 0.15$

2. Linear thermal transmittance ($\Psi$) can be determined by numeric modelling/measurement.
   a. $\Psi$-values for junction details based on a range of target U-values for plane elements are listed in TGD Part L - Table D1-D6.

Air infiltration

Heat lost due to un-designed Infiltration losses are measured by the volume of air changes that occur every hour based on the floor area of the building. ($m^3/hr/m^2$)

Performance levels of $7m^3/hr/m^2$ is stated as the upper limit for air permeability for natural ventilation and values less than $5m^3/hr/m^2$ when mechanical ventilation is employed.

The rate of air change will be affected by the volume of air within the building, the scale of air infiltration, the number, size and location on air vents, open flues and the pressure induced by the magnitude and direction of the prevailing wind. As heat flows
from warm to cold areas, the temperature difference between inside and outside is also an important factor.

Air infiltration losses are derived from

\[ \text{Air infiltration losses} = 0.33Nv\Delta T \]

\( N \): Air infiltration rate (ac/hr)
\( v \): Volume enclosed by the building (m\(^3\))
\( \Delta T \): Temperature difference between inside and outside. (\(^\circ\)C or K)

**Note:** for the purposes of calculations, the infiltration rate (N) refers to the air changes per hour for typical inside/outside pressure differences under normal operating conditions (50Pa). This is calculated by dividing the value for air permeability measured at 50 Pascal (q50) by 20 (see DEAP manual Section 2.3)

**Total heat loss**

As mentioned earlier, the total heat loss is the sum of all the losses through the fabric as well as due to air infiltration. This can be expressed using

\[ Q = \sum UA\Delta T + 0.33Nv\Delta T \]

\( Q \): Total Heat Loss rate (w)
\( U \): U value Thermal transmittance (W/m\(^2\)K)
\( A \): Surface area through which heat transfer occurs (m\(^2\))
\( \Delta T \): Temperature difference between inside and outside. (\(^\circ\)C or K)
\( N \): Air infiltration rate (ac/hr)
\( v \): Volume enclosed by the building (m\(^3\))

![Figure 2.20: Graphic illustrating total heat loss in a building](image)
Note: this equation does not account for heat losses due to linear thermal transmittance ($\Psi$). As this value is dependent on the detail within the structural elements, inputs required in DEAP software will account for this using one of the methods described earlier in the assessment of overall heat transfer rates.

**Example 1: Overall Heat Loss**

Calculate the overall heat loss ($Q$) using the measured U-values and air infiltration rates outlined for the semi-detached building below for a temperature difference of 16°C.

**Building Specification**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Description</th>
<th>U-Value W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>Cavity Wall with 100mm insulation</td>
<td>0.25</td>
</tr>
<tr>
<td>Roof</td>
<td>Cold Roof with 270mm quilt insulation between and over ceiling joists</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor</td>
<td>Ground floor concrete slab with 100mm insulation</td>
<td>2.00</td>
</tr>
<tr>
<td>Windows</td>
<td>25% of total floor area</td>
<td>1.70</td>
</tr>
<tr>
<td>Door</td>
<td>Solid wooden door 1.85m²</td>
<td>3.00</td>
</tr>
<tr>
<td>Infiltration</td>
<td>7m³/hr/m² = (7/20) = 0.35 ac/hr</td>
<td></td>
</tr>
<tr>
<td>Internal Temp</td>
<td><strong>21°F</strong></td>
<td></td>
</tr>
<tr>
<td>External Temp</td>
<td><strong>5°F</strong></td>
<td></td>
</tr>
</tbody>
</table>

- Identify thermal boundary
- Calculate Fabric heat loss
- Calculate infiltration heat loss
Note: Heat loss through the party wall is not counted as contributing to heat loss for the overall structure.

**Plane element heat losses = $U \times A \times \Delta T$**

<table>
<thead>
<tr>
<th>Surface</th>
<th>U-Value W/m²K</th>
<th>Sizes/m</th>
<th>Overall Area/m²</th>
<th>Wall - door Area/ m²</th>
<th>Net Area/ m²</th>
<th>$\Delta T$ °C</th>
<th>$AU\Delta T$ W/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>0.25</td>
<td>23.0</td>
<td>5.0</td>
<td>115</td>
<td>115.41</td>
<td>16</td>
<td>346.24</td>
</tr>
<tr>
<td>Roof</td>
<td>0.15</td>
<td>9.0</td>
<td>7.0</td>
<td>63</td>
<td>63</td>
<td>16</td>
<td>151.2</td>
</tr>
<tr>
<td>Floor</td>
<td>0.2</td>
<td>9.0</td>
<td>7.0</td>
<td>63</td>
<td>63</td>
<td>16</td>
<td>201.6</td>
</tr>
<tr>
<td>Windows</td>
<td>1.7</td>
<td>25% of wall</td>
<td>28.85</td>
<td>16</td>
<td>784.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td>3</td>
<td>0.9</td>
<td>2.1</td>
<td>1.89</td>
<td>1.89</td>
<td>16</td>
<td>90.72</td>
</tr>
</tbody>
</table>

**Overall fabric heat loss through plane elements** = 1574.5 Watts

**Air infiltration losses = $0.33Nv\Delta T$**

$\Delta T$ : $21^\circ C - 5^\circ C = 16^\circ C$

$N$ : $7 \div 20 = 0.35$ ac/hr

$v$ : Volume enclosed by the building = $9 \times 7 \times 5.1 = 321.3$ m³

Air infiltration losses = $0.33 \times 0.35 \times 321.3$ m³ $\times 16$

Air infiltration losses = 593.76 Watts

Total heat loss can be determined by calculating the sum of all the losses through the fabric and all losses due to air infiltration.

$$Q = \sum UA\Delta T + 0.33Nv\Delta T$$

$Q = 1547.5 + 593.76$

$Q = 2,141$ Watts

**Overall Heat Loss $Q = 2.14$ kW**
In this example, infiltration accounts for almost 30% of the total heat lost when using a q50 air permeability rating of 0.35. Significant levels of heat loss can be attributed to air infiltration, even at the standards set in the current building regulations.

The impact of air infiltration can be clearly illustrated using the results from the example calculation above and adapted for three different q50 air permeability standards (N) for comparison purposes.

<table>
<thead>
<tr>
<th>Air Change m³/hr/m²</th>
<th>N - AC/hr q50</th>
<th>Category</th>
<th>Heat Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>18m³</td>
<td>0.9</td>
<td>Leaky – Typical Pre 2008</td>
<td>1,563</td>
</tr>
<tr>
<td>10m³</td>
<td>0.5</td>
<td>Improved – 2008 Building standards</td>
<td>848</td>
</tr>
<tr>
<td>7m³</td>
<td>0.35</td>
<td>Reasonable – 2011 Building standard</td>
<td>594</td>
</tr>
<tr>
<td>0.6m³</td>
<td>0.03</td>
<td>Tight - Passive house standard</td>
<td>51</td>
</tr>
</tbody>
</table>

For the purpose of distinction, the different standards have been categorised as Leaky, reasonable, and tight. The “tight” standard is equivalent to a q50 of 0.6 ac/h, the maximum level of air permeability permitted for Passive House.

<table>
<thead>
<tr>
<th>Effect of Air infiltration on overall heat loss</th>
<th>Category</th>
<th>N - AC/hr q50</th>
<th>Overall heat loss - Watts</th>
<th>% Heat loss due to air infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaky</td>
<td>0.9</td>
<td>3,110</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>0.5</td>
<td>2,396</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>Reasonable</td>
<td>0.35</td>
<td>2,141</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>Tight</td>
<td>0.03</td>
<td>1,598</td>
<td>3%</td>
</tr>
</tbody>
</table>
Summary

- Heat – governed by the laws of thermodynamics, is lost from buildings as soon as the energy is converted. The heat is lost through the fabric of the building, mainly due to conduction and through air infiltration – usually due to convection.

- The rate of heat loss through the fabric of the building is dependent on
  - Temperature difference between inside and outside
  - Surface area of the building
  - Thermal properties of the building materials

- With a greater air temperature difference between inside and outside during colder months, the rate of heat flow is accelerated through the building fabric. Heat loss is the measure of a building’s thermal transmittance and is denoted as a U-value.

- The building regulations govern the maximum permitted U-values for all the plane elements of the building, floors, walls, roofs, windows, and doors. As building regulations have become more stringent, structural elements must incorporate materials with lower levels of thermal conductivity (λ Lambda) in the construction to remain compliant.

- Every material within the structural elements enclosing the building will contribute to heat loss including the air resistance layers both inside and outside the building. When the thermal properties of the materials within an element differ, the rate of heat loss through one of the elements is accelerated causing a thermal bridge. Heat loss calculations must account for thermal bridging including linear thermal bridging when establishing the overall elemental u-values.

- Adequate ventilation is a very important factor in controlling moisture and also for comfort levels within the living space however, uncontrolled air infiltration can have a huge impact on the rate of heat lost regardless of the levels of thermal resistance incorporated into the structural elements.

- It is in the interest of designers, builders, and owners to minimise the levels of heat loss and as a result, reduce associated energy costs involved with heating their buildings. To minimise overall heat loss, the structural fabric of the building must be designed and constructed in such a way as to resist the passage of heat through conduction and to eliminate uncontrolled air infiltration.
1. Describe how heat-loss from buildings is categorised?
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

2. Outline what is meant by the following terms including units of measurement
   1) Thermal Transmittance :_________________________________________
      _______________________________________________________________
      _______________________________________________________________
      _______________________________________________________________
   2) Thermal Conductivity :___________________________________________
      _______________________________________________________________
      _______________________________________________________________
      _______________________________________________________________
   3) Thermal Resistance :____________________________________________
      _______________________________________________________________
      _______________________________________________________________
      _______________________________________________________________

3. To what extent does each of the structural elements of the fabric contribute to overall heat loss?
   Floor : _____________________________________________________________
   _________________________________________________________________
   Walls : _____________________________________________________________
   _________________________________________________________________
   Roof : _____________________________________________________________
   _________________________________________________________________
   Windows & Doors : _________________________________________________
   _________________________________________________________________
4. What is “Air Surface resistance” and how is it measured?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

5. Describe how U values are calculated for plane element structures with no thermal bridging “In Series”.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

6. Describe how U values are calculated for plane element structures with thermal bridging “In Parallel”.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

7. How does cold/warm roof construction affect U-value calculations?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

8. How are U-values for windows and doors determined?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

Unit 2 section 1
Unit 2 Section 2
Measuring Performance with DEAP
2.1 Introduction

This section is designed to provide guidance on the inputs required in the Ventilation and Building Elements tabs of Dwelling Energy Assessment Procedure (DEAP) software. These are the sections in DEAP where the building fabric performance is evaluated, with air permeability of the dwelling and thermal bridging in the envelope accounted for.

In order to complete an assessment, a range of data on building fabric characteristics are entered in DEAP including construction type, dimensions and U-values. In the case of windows, further details such as orientation and shading levels are required.

This section provides an opportunity for you to build on your prior knowledge of construction while drawing upon the learning from previous sections of the module. It is important to have an understanding of how DEAP evaluates the performance of the building fabric so that you can relate this to the construction/renovation process. It is then possible to consider the implications of the assessment procedure on the challenges facing construction workers tasked with implementing building standards.

At the end of this section, you will be able to:

1. Select and describe appropriate data required in DEAP for assessing building fabric performance

2. Reflect on some of the factors affecting building fabric performance, as determined in DEAP, that are directly related to the building construction/renovation process

Note: this section references the following source material:

2.2 Ventilation

The Ventilation section of DEAP is where information is inputted to establish the air permeability of the dwelling. The software considers air infiltration due to openings which have been intentionally provided for ventilation purposes. In the absence of an air permeability test, air infiltration due to structural air tightness is assessed. The exposure of the dwelling to wind pressures and the ventilation method are also taken into account.

Openings

The Openings section considers the penetrations of the building fabric that have been intentionally designed to provide air change in the dwelling. These include the following:

- Chimneys – number of open chimneys with a diameter of 200mm or more
- Open flues – number of chimneys or flues with a diameter less than 200mm
- Passive vents – number of hole-in-wall or window trickle vents with a cumulative open area in a room greater than 3500 mm²
- Intermittent vents – number localised mechanical extract vents which operate intermittently, e.g. extractor hood in kitchen, bathroom extract vent
- Flue-less combustion heaters – number of fixed flue-less combustion devices that are deemed to require both a high level and low level permanent vent

The contribution to air change for each that is allowed for in DEAP is given in Table 2.5

Table 2.5 Ventilation rates for openings in DEAP

<table>
<thead>
<tr>
<th>Opening Type</th>
<th>Ventilation Rate m³/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chimney</td>
<td>40</td>
</tr>
<tr>
<td>Open Flue</td>
<td>20</td>
</tr>
<tr>
<td>Intermittent Fan</td>
<td>10</td>
</tr>
<tr>
<td>Passive Vent</td>
<td>10</td>
</tr>
<tr>
<td>Flue-less Combustion Heaters</td>
<td>40</td>
</tr>
</tbody>
</table>
The ventilation rates illustrate the level of air change that occurs in a dwelling through chimneys and flues. Often, there are chimneys and flues that are left open to accommodate combustion devices, but which are seldom or sometimes never used, leading to unnecessary air change and heat loss.

Also considered in the Openings section is the provision of a draught lobby at the dwelling entrance. Where a draught lobby is present the air changes affected by occupants entering and leaving a dwelling are greatly reduced. An air lock is effectively created when an inner door is closed before opening the external door or vice-versa. DEAP allows for an additional 0.05 air changes per hour (ac/h) where there is no draught lobby present.

**Structural air-tightness**

This section assesses the air infiltration in a dwelling which is affected by the type of structure. The software automatically calculates for air infiltration due to the number of storey’s in the dwelling (based on previously inputted information in ‘Dimensions’ tab). The structure type is then selected from the following options:

- Masonry – traditional concrete block construction in single layer or twin layer (cavity wall) or solid concrete construction (in-situ or precast)
- Timber or Steel Frame – construction where timber or steel frame is responsible for the load bearing capacity of the structure
- Insulated Concrete Form – concrete cast in-situ sandwiched between two layers of insulation which remain permanently in place

All of these types of construction have characteristics which traditionally affect their levels of structural air tightness and are estimated accordingly in DEAP.

The next input which requires you to specify if there is a suspended timber floor present (see Figure 2.21). Typically, this type of floor construction has a poor insulation value and is considered to be particularly prone to air leakage. This is often exacerbated in cases where there is no floor covering above and/or the joints between the flooring boards have been disturbed to install services. In these instances, cold external air which is ventilating the area under the floor enters rooms through the gaps in the construction.
The next entry is the percentage of windows and doors in the dwelling that are draught-stripped. This refers to the provision of air tight connections between the open able parts, such as window casement/sash and doors, and the frames that house them. The number of windows, doors and attic hatches with draught-stripping installed should be added together and divided by the total number present in the dwelling. Figure 2.22 illustrates typical seal installations and applications for windows and doors.

Correct installation and maintenance are required to ensure that draught-proofing measures for windows and doors are effective. Poorly fitted windows or doors can often lead to opening elements not seated properly and engaging with draught seals. Settlement and distortion of these elements can also occur over time and leading to similar problems with air leakage.
Another factor affecting air infiltration that is accounted for in DEAP is the number of sheltered sides in the building. A side of the building is considered to be sheltered if there are immediately adjacent buildings or trees/hedges which obstruct wind. Obstacles to the wind must at least reach the ceiling height of the uppermost storey of the dwelling. The distance between the obstacle and the dwelling should be less than five times the height of the obstacle to be considered. Further guidance on partially sheltered sides is available in the DEAP manual.

**Selection of Ventilation Method**

The final step in DEAP requires the selection of the applicable ventilation method from a drop-down menu with the following options:

- Natural ventilation – this refers to the provision of permanent vent openings in walls or windows with intermittent mechanical extract provided in wet rooms (e.g. kitchen and bathroom)
• Positive input ventilation from loft – a system which uses a fan to force fresh air into a dwelling, creating a positive pressure which pushes stale air out through trickle vents. Where the fan is located in the loft, the fresh air is preheated slightly by the higher ambient temperature of the attic space. This heat gain can usually offset the energy used to operate the fan

• Positive input ventilation from outside – same as above but with the fan located on an external wall rather than in the loft space

• Whole-house extract ventilation – a fan driven ventilation system, which can be centralised or localised, running continuously to extract air. Fresh air is not provided to the dwelling by this system

• Balanced whole-house mechanical ventilation, no heat recovery – this is a fan driven ventilation system which provides fresh air to rooms and extracts stale (exhaust) air from the dwelling. The fan is usually locate centrally (often in loft space) and piped to individual rooms or areas to provide intake and exhaust.

• Balanced whole-house mechanical ventilation with heat recovery – same as above but with the addition of a heat recovery unit within the fan which transfers heat energy from exhaust air to preheat incoming fresh air (see Figure 2.23).

Figure 2.23: Typical Mechanical Heat Recovery Ventilation (MVHR) Layout

Ventilation systems are described in more detail in the Module 3 manual of this programme.
2.3 Floors

In the Floors section of the ‘Building elements’ tab of DEAP, information is inputted in relation to floor type, dimensions and U-value. DEAP allows for different characteristics of the floor of the dwelling to be assessed separately, e.g. where the main floor of a dwelling is one construction and an extension added later is another. In this case, the area of each section of the floor and the U-value for each can be added.

The following sections describe the floor type selections available in DEAP and, where appropriate, relate them to the implications for energy performance in the construction/renovation process.

Floor type

The first step for the assessment of the ground floor is to select the appropriate floor type from a drop-down menu. The following is a description of each of the floor types.

Solid Ground Floor

This refers to a concrete slab-on-ground construction which is commonly used in Ireland. This type of construction consists of a slab of concrete laid on top of a bed of hardcore fill (see Figure 2.24). When DEAP is used to assess an existing dwelling, the software will automatically select a default U-value for the floor based on an age band for the building. For existing dwellings, DEAP will require both the area of the floor and the linear meters of exposed perimeter (where floor meets external walls).

![Figure 2.24: Un-insulated Concrete slab-on-ground floor(Reproduced from S.R. 54:2014 with the permission of NSAI)](image-url)
Concrete slab-on-ground floors subject to 2002 Building Regulations and after are required to have insulation under the slab and on all exposed perimeters (see Figure 2.25). Therefore, DEAP only requires a linear measurement of exposed ground floor perimeter for existing dwellings.

Figure 2.25: Insulated concrete slab-on-ground floor construction (Reproduced from S.R. 54:2014 with the permission of NSAI)

Suspended Ground Floor

There are three forms of suspended floors commonly used in construction in Ireland:

- Suspended/raised timber ground floor (see Figure 2.21 Previously)
- Precast hollow core suspended floor (see Figure 2.26)
- Precast block and beam suspended floor (see Figure 2.27)

Similarly to the concrete slab-on-ground floor, for existing dwellings, DEAP requires area of floor in square meters and the number of linear meters of exposed perimeter.

The suspended timber floor, as mentioned previously in the ‘Ventilation’ section, is prone to air leakage and poor thermal insulation levels. The performance can be improved by fitting insulation between floor joists and applying an air tight membrane over which is connected at the junctions with the external walls. However, to retrofit such a floor to this standard requires removal (and usually replacement) of the existing floor covering and floorboards. The upgraded floor insulation is also affected by repeated thermal bridging at every floor joist.
For the two precast concrete suspended floor options, the same principles for the insulation layer as those for concrete slab-on-ground apply, i.e. continuous insulation under screed and perimeter insulation fitted tightly to the main insulation.

Figure 2.26 Suspended concrete floor with internally insulated walls (source: TGD L 2011)

Figure 2.27: Block and beam suspended floor (source: TGD L 2011)
**Ground Floor – Above Unheated Basement**

An unheated basement is not considered as part of the floor area assessed in DEAP. The ground floor above the unheated space is considered as the heat loss area and calculated accordingly. Once again, as with slab-on-ground and suspended floors, the area of the floor and the linear measurement of the exposed perimeter are required. Where there is insufficient information available about the construction of the floor to calculate the actual U-value, the default values provided in DEAP should be used (see example in Figure 2.28).

![Figure 2.28: Example of an unheated basement in DEAP](image)

**Partially Heated Below**

This refers to a floor above a space that is only heated occasionally or intermittently, i.e. not to the same temperature or pattern of the dwelling. An example would be the floor of an apartment above a commercial unit.

**Exposed/Semi-Exposed**

This refers to a floor that is wholly or partially overhanging the main building and exposed to external temperatures, e.g. a first floor apartment with a section of the floor overhanging the ground floor building line (see Figure 2.29).
Heated Basement – walls exposed to ground

If a basement is heated as a habitable room/s consistent with the main dwelling, then it is treated as part of the total floor area of the dwelling. The floor above the heated basement is no longer considered as a heat loss area. However, heat is lost from the floor and walls of the basement and must be accounted for and calculated in DEAP.

2.4 Roofs

The Roofs section in DEAP considers the different types of roof construction commonly found in Ireland. It is necessary to input the area for each of the different types of roof construction (note: roof area is net of any roof windows set in roof). In Ireland, it is common to have different roofs or roof characteristics in the same dwelling. For example, the main part of a dwelling may have a pitched roof, but with a flat roof extension. Also, within the same roof structure, part of a ceiling may be sloped to follow the rafter line of a pitched roof while the rest is horizontal. These two parts of the same roof need to be treated separately in DEAP as they will have different heat loss characteristics.
### Roof type

A warm or cold roof is defined by the position of the insulation layer/s either being positioned on the inside or the outside of the structure. The following sections describe the different roof types that may be selected in DEAP. Where appropriate, reference is made to factors affecting energy performance that are related to the construction/renovation process.

#### Pitched Roof – Insulated on rafter

Insulating a pitched roof at the rafters is most common when rooms are accommodated in the roof space. It is also necessary when vaulted ceilings are formed in rooms, i.e. the ceiling is defined by the internal line of the pitch roof, creating a high open effect.

A pitched roof may be insulated on rafter either as a cold roof (see Figure 2.30) or a warm roof construction (see Figure 2.31). The cold roof option involves the installation of insulation between and/or below the rafter. It is essential that the insulation fitted between rafters does not interfere with the through ventilation provision for the roof which should allow the free passage of air from eaves to eaves. A continuous gap of 50 mm minimum between the insulation layer and the roof felt (top of rafter) is required.

For a warm roof construction, the insulation is installed above (and sometimes between) the rafters. While the risk of surface condensation is minimised, a vapour control layer should still be provided to prevent interstitial condensation and improve air tightness. TGD L 2011 states “Only systems which are certified or shown by test and calculation as appropriate for this function” should be used.
Figure 2.30: Cold pitched roof insulated between and below rafters (Reproduced from S.R. 54:2014 with the permission of NSAI)

Figure 2.31: Warm pitched roof insulated between and above rafters (Reproduced from S.R. 54:2014 with the permission of NSAI)
Pitched Roof – Insulated at Ceiling

This is where the pitched roof is insulated at the horizontal ceiling level dividing the room from the unheated roof space. Traditionally, a single layer of insulation was fitted between the ceiling joists. In line with recent requirements of building regulations for improved U-values and counteracting thermal bridging effects, an additional insulation layer is placed above the ceiling joists and first layer (see Figure 2.32).

It is essential to maintain ventilation pathways to ensure through ventilation, therefore, the insulation must be carefully installed. Attention should also be given to continuity of insulation at junctions with external walls.

Figure 2.32: Pitched roof insulated on ceiling (Reproduced from S.R. 54:2014 with the permission of NSAI)

Flat Roof

Flat roofs are found in Irish dwellings as either as concrete or timber constructions (see Figure 2.33). Similar to pitched roofs, they are available in warm or cold roof variants.
Cold roof timber versions are insulated between (and sometimes below) the joists. Ventilated air space above the insulation is particularly important in flat roof construction as there is a higher possibility of water ingress than with pitched roof as well as the risk of interstitial condensation (Figure 2.35).

Figure 2.35: Timber flat roof – cold deck construction with insulation between and below joists (source: TGD L 2011)

Concrete flat roofs are often insulated on the outside (warm roof). A vapour barrier should be installed between the concrete slab and the insulation layer to prevent interstitial condensation (see Figure 2.35).
Room in Roof – Insulated on side

This refers to room in roof dormer type dwellings or loft conversions with insulation fitted to the knee (short side) walls. The knee walls and ceiling sections above the room below are regarded differently for heat loss calculation to the room in roof flat and sloping ceiling sections. As per TGD L 2011 (see Figure 2.36) the resistance of the unheated airspace (Ru) above the flat ceiling of the room in roof is considered as 0.2 m²K/W (as per standard roof) whereas the Ru of the roof space adjacent to the knee walls and above the ceiling of the room below is given as 0.5 m²K/W.

Traditionally, knee walls have been neglected from an insulation perspective with a single layer fitted between the timber studs. It is good practice to place additional layers of insulation on the warm or cold side of the stud wall to improve performance and counteract thermal bridging effects. An airtight vapour control membrane installed on the warm side will prevent against air leakage and interstitial condensation (see Figure 2.37). Particular attention should be given to insulation and draught-proofing of access doors.
Figure 2.36: Calculating heat loss for room in roof (source: TGD L 2011)

Figure 2.37: Section through room in roof with ventilation requirements shown with knee (side) wall circled (Reproduced from S.R. 54:2014 with the permission of NSAI)
2.5 Walls

Input to DEAP requires information on the area and U-value of each exposed/semi-exposed wall construction in the dwelling (semi-exposed refers to walls adjacent to unheated spaces, e.g. garage, stairwell in apartment building). Wall area is the net area of wall after subtracting for total area of openings for windows and doors. A dropdown menu provides multiple selection options for external walling. Selection from this menu allows DEAP to apply default U-values for existing dwellings or identify compliance with building regulations for new dwellings.

For the purpose of clarity, wall type selections have been divided into three categories in the following sections:

1. Single leaf walling – which covers stone, solid brick, solid mass concrete and hollow block walls
2. Twin leaf walling – which covers the different variations and sizes of cavity walls
3. Timber frame walling

Single Leaf Walling

DEAP analysis includes a number of single leaf options such as stone, 225mm solid brick, 325 mm solid brick, solid mass concrete and concrete hollow block walls. It is often possible to investigate wall construction type in an existing dwelling by removing internal covers of wall vents or checking inside wall recessed gas/electricity meter boxes. Wall thicknesses can be established by measuring reveal depths at openings, allowing where appropriate for render thicknesses and window/door frame dimensions.

Hollow block walling was used extensively between the 1960's and 1990's in residential construction, particularly in the Leinster region. This construction type has very poor thermal performance. After the oil crisis in the 1970's, it became commonplace to dry line hollow block walls and other existing single layer walls to reduce heat loss. This often consisted of a single layer of insulation material fitted between vertical wall fixed timber battens (see Figure 2.38) with no insulation applied to the reveals at openings. These systems suffered greatly with repeated thermal bridging (at battens) and condensation around openings and at junctions.
Twin Leaf Walling

Masonry cavity walling has become perhaps the most commonly used in residential construction since the 1960's. Two leaves of masonry wall are constructed with a ventilated air cavity between (usually 100 mm). The outer leaf may be brick, stone or concrete block, depending on the desired finish, with a concrete block commonly forming the inner leaf. The two leaves are connected for structural strength using steel or plastic cavity ties bedded into the joints at intervals.

This type of wall construction is favoured as it prevents water ingress from the outside. Any moisture penetrating the outer leaf will not bridge the air cavity and will have an opportunity to dry out harmlessly. As awareness of energy saving and insulation increased after the oil crisis of the 1970's, an insulation layer was installed in the cavity against the inner leaf (see Figure 2.39). This improved thermal performance of the wall while maintaining a cavity to prevent water ingress.
DEAP offers options of a 300 mm and 425 mm cavity or filled cavity wall. The 300 mm wall consists of two 100 mm leafs with a 100 mm air cavity. The 425 mm variant has a 225 mm inner leaf (concrete block on flat). In recent years, some cavity walls have had insulation pumped in to fill the cavity as a retrofit measure for improved thermal performance (see Unit 3 Section 2 later).

Insulating a 100 mm cavity, while maintaining a 40 mm minimum air space (TGD L 2011), limits the thermal performance that can be achieved with a single insulation layer. A common approach is to increase the cavity size to accommodate thicker cavity insulation or install additional insulation on the warm side (dry lining). Attention is also needed at openings and junctions to avoid thermal bridging.
Timber frame construction has become increasingly popular in recent years in Ireland, as it provides the possibility of prefabrication offsite which can considerably speed up the build. Timber frame also gained a reputation for providing warmer homes as thick insulation layers are readily accommodated between stud and joist frames in the building elements.

Traditionally, a single layer of insulation was installed between timbers (see Figure 2.40). This approach results in a repeated thermal bridging effect. As air permeability testing was introduced to the construction sector, many timber frame dwellings performed relatively poorly. Newer approaches are now often adopted which emphasise the energy performance potential of timber frame, incorporating air tightness and thermal bridging detailing into the design.

Figure 2.40: Example of a traditional Irish timber frame wall construction (Reproduced from S.R. 54:2014 with the permission of NSAI)
2.6 Doors and Windows

Door and window areas in DEAP refer to the total area of the openings including frames. The U-values for solid doors and glazing are derived from Table B1 of TGD L 2011 (see Figure 2.41 below). The adjustments for frame type are also matched to the figures provided in TGD L notes.

<table>
<thead>
<tr>
<th>Table B1</th>
<th>Indicative U-Values (W/m²K) for windows, doors and rooflight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of frame</td>
</tr>
<tr>
<td></td>
<td>6 mm gap</td>
</tr>
<tr>
<td>double-glazed, air filled</td>
<td>3.1</td>
</tr>
<tr>
<td>double-glazed, air filled (low-E, Ån = 0.2, hard coat)</td>
<td>2.7</td>
</tr>
<tr>
<td>double-glazed, air filled (low-E, Ån = 0.15, hard coat)</td>
<td>2.7</td>
</tr>
<tr>
<td>double-glazed, air filled (low-E, Ån = 0.1, soft coat)</td>
<td>2.6</td>
</tr>
<tr>
<td>double-glazed, argon filled (low-E, Ån = 0.05, soft coat)</td>
<td>2.6</td>
</tr>
<tr>
<td>double-glazed, argon filled (low-E, Ån = 0.2, low-E)</td>
<td>2.5</td>
</tr>
<tr>
<td>double-glazed, argon filled (low-E, Ån = 0.15, hard coat)</td>
<td>2.5</td>
</tr>
<tr>
<td>triple-glazed, air filled</td>
<td>2.1</td>
</tr>
<tr>
<td>triple-glazed, air filled (low-E, Ån = 0.2, hard coat)</td>
<td>2.1</td>
</tr>
<tr>
<td>triple-glazed, air filled (low-E, Ån = 0.15, hard coat)</td>
<td>2.0</td>
</tr>
<tr>
<td>triple-glazed, air filled (low-E, Ån = 0.1, soft coat)</td>
<td>2.0</td>
</tr>
<tr>
<td>triple-glazed, argon filled (low-E, Ån = 0.2, hard coat)</td>
<td>1.9</td>
</tr>
<tr>
<td>triple-glazed, argon filled (low-E, Ån = 0.15, hard coat)</td>
<td>1.8</td>
</tr>
<tr>
<td>triple-glazed, argon filled (low-E, Ån = 0.1, soft coat)</td>
<td>1.8</td>
</tr>
<tr>
<td>triple-glazed, argon filled (low-E, Ån = 0.05, soft coat)</td>
<td>1.7</td>
</tr>
<tr>
<td>Windows and doors, single-glazed</td>
<td>4.8</td>
</tr>
<tr>
<td>Solid wooden door</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Figure 2.41: Indicative U-values for windows, doors and rooflight (sources: TGD L 2011)

Non-default U-values can be inputted only if supported by acceptable certified documentation from the door/window manufacturer. It should be noted that the default U-value for a solid door is 3.0 W/m²K. It should be noted that glazed doors are considered as those with 30% - 60% glazing and U-value can be calculated manually or a certified manufacturer’s value applied. Those with glazing percentage greater than 60% are considered as windows in DEAP.

The inputs required for doors are relatively straightforward, requiring only number, area and U-value. Windows, however, require a number of additional inputs including:

- Glazing type – to determine the heat loss of glazed area
- Frame type – to determine the heat loss of frame
- Overshading – to account for effect on solar gains
- Orientation – to account for solar gain
- Where non-default U-values are applied, the solar transmittance value as per manufacturers certified data, again to account for effect on solar gain
Glazing type

Heat transfer through the glazed sections of a window is affected by a number of factors including:

- The number of panes of glass, i.e. single, double or triple glazed
- For double or single glazing, the gas used to fill the cavity between panes and the depth of this space
- Coatings on the glass that affect solar and/or thermal transmission
- The material used for the cavity spacer

Currently, single glazing is rarely used in Ireland. Glass on its own offers a low level of thermal resistance (approximately 0.006 W/m²K for a 6 mm glass pane). Double glazing and triple glazing offered the possibility to introduce a layer of still dehydrated air, an excellent insulator, between the panes of glass in a window.

This thermal resistance can be further enhanced through the use of other gases as a substitute for air. Argon is the most commonly used gas in window manufacturing as a substitute for air. Argon has a 34% lower conductivity for an approximately 5% increase in cost. Krypton and Xenon, which are significantly more expensive, are occasionally used in projects where higher performance is required.

Low emission coatings are used to further enhance the energy performance of glazing units. The coatings applied to glass are microscopically thin and transparent. They work by reflecting long wave infra-red light (heat) back into a room, reducing the radiant heat loss through the glass. The ability of a material to radiate energy is known as emissivity, hence the name low-E glass.

Uncoated glass has an emissivity of 0.84, while low-E glass varies between 0.2 and 0.05. There are two variants available as follows:

- Hard coat – with emissivity of 0.2 to 0.15. Hard coat Low-E glass is manufactured by applying the coating during production and fusing it to the hot glass surface forming a strong hard coat.
- Soft coat – with emissivity of 0.1 to 0.05. For soft coat, the coating is applied to pre-cut sections of glass in a vacuum chamber. It is not as durable as hard coat and is usually applied to the cavity side of the inner pane for protection (see Figure 2.42).

The material used to separate the panes of glass, known as the cavity spacer, also determine rate of heat transfer where they are located. Aluminium or plastic are most
commonly used with the higher conductivity of the metal variant resulting in increased
heat loss.

Figure 2.42: Solar transmittance through double Glazed unit (Reproduced from S.R. 54:2014 with the permission of NSAI)

Frame type

From the frame type menu in DEAP, it is possible to select either Wood/PVC or
different variants of metal frame. Metal, as a highly conductive material, is less
favourable from a heat loss perspective than wood or PVC. However, this conductivity
can be significantly decreased by incorporating a thermal break (usually plastic) into
the frame section (see Figure 2.43). DEAP offers a number of options in the menu for
frames to reflect different thicknesses of thermal break available for metal windows.
NSAI have developed a Window Energy Performance (WEP) rating which provides a value for the overall energy performance of the window taking into account U-value of whole window unit, air leakage and solar transmittance. This information is provided through a labelling system similar to that for energy rating of household appliances (see Figure 2.44). The values on the label can be inputted in DEAP.
Overshading and Orientation

The solar gain potential through glazed areas in the building fabric is strongly affected by both orientation of the building and shading (see Unit 1 Section 1). The DEAP analysis requires windows to be considered separately for each elevation of the dwelling, depending on orientation. The orientation is selected from the options in the dropdown menu from North, North East/ North West, East/West, South East/ South West, South and Horizontal (selected for rooflights).

Overshading is an estimate of the sky which is blocked by objects measured from the centre point of the window being considered (see Figure 2.45). Objects obscuring the skyline below the centre point should be ignored. Those obscuring the skyline above the centre point which are close to the window, e.g. balconies, reveals, soffits, should be considered as well as those further away, such as landmasses and other buildings. Selection options available in DEAP for overshading are ‘Average or Unknown’, ‘Very Little’, ‘More Than Average’ or ‘Heavy’.

Figure 2.45: Estimating overshading (source: SEAI BER Technical Bulletin 2009)
2.7 Heat Loss Results

The last page of the Building elements tab is the ‘Heat loss results’. This generates separate summaries of the heat loss as calculated for windows and the combined totals for the entire building fabric. Total heat loss is expressed in W/K m².

There is only one input that can be edited on this page, the factor for thermal bridging, known as the y value. DEAP automatically selects a default y value of 0.15 W/m²K (see Figure 2.46). This can only be changed in one of three instances:

1. **y = 0.08 W/m²K** may be inputted where a new dwelling conforms to “Limiting Thermal Bridging and Air Infiltration – Acceptable Construction Details” as referenced in the 2008 and 2011 Building Regulations. The relevant construction details must be signed off by the architect, developer, site engineer or building contractor.

2. **y = 0.11 W/m²K** may be inputted for dwellings where 2005 Building Regulations have applied. The relevant construction details must be signed off by the architect, developer, site engineer or building contractor as compliant with details from TGD L 2005 or Homebond “Right on Site” manual publications from this year on.

3. **Lower values** can be inputted where junction details have been numerically modelled and certified by a member of the NSAI Thermal Modeller’s Certification Scheme (as per conditions in TGD L 2011).

![Figure 2.46: Heat loss results page with default factor for thermal bridging circled](image)
Summary

- Heat loss due to air changes is calculated in the Ventilation section of Dwelling Energy Assessment Procedure (DEAP). Air change is considered under three headings: Openings, Structural air-tightness and Ventilation.
- Openings include designed wall vents, both passive and mechanical intermittent vents, number of open chimneys/flues and the existence of a draught lobby at entrance.
- Structural air-tightness is defined by the structure type and the level of draught-proofing at windows/doors or the results of an air permeability test.
- Ventilation air changes are determined by the ventilation method as selected from options available for natural ventilation, positive input ventilation or mechanical ventilation.
- The 'Building elements' section requires data for doors, floors, walls and roofs that includes construction type, area, U-value and exposure.
- Default U-values are applied for assessments of existing dwellings based on construction type and the age band of the dwelling.
- Windows require additional information including glazing type, frame type, overshading levels, orientation and solar transmittance value.
- A default factor for thermal bridging (y value) of 0.15 W/m²K. Lower values may only be inputted in instances where guidelines in the building regulations allow for certification or sign off of details used in construction.
Further Reading


1. Under what three headings does the DEAP section on Ventilation account for heat loss due to air changes?
   1) _______________________________________________________
   2) _______________________________________________________
   3) _______________________________________________________

2. List the ventilation rates for each of the following opening types expressing your answer in m³/hour
   1) Open flue_______________________________________________
   2) Passive vent____________________________________________
   3) Chimney________________________________________________
   4) Fan (intermittent)________________________________________

3. Describe how the results of an air permeability test may be converted to give an estimate of the air change rate (ac/h) in typical pressure differences under normal operating conditions
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

4. Name and briefly describe each of the four roof-type options available in DEAP
   1) _______________________________________________________
   2) _______________________________________________________
   3) _______________________________________________________
   4) _______________________________________________________

Unit 2 section 2
5. Define the percentage range of glazed area that defines a glazed door in DEAP

______________________________________________________________

______________________________________________________________

6. What is the default U-value in DEAP for a solid timber door?

______________________________________________________________

7. Describe the significance of window orientation in the calculations for energy performance of windows in DEAP

______________________________________________________________

______________________________________________________________

______________________________________________________________

8. Name and describe each of the three instances when a lower than default y value can be entered in the heat loss results page in DEAP

1) _______________________________________________________

_______________________________________________________

_______________________________________________________

_______________________________________________________

2) _______________________________________________________

_______________________________________________________

_______________________________________________________

_______________________________________________________

3) _______________________________________________________

_______________________________________________________

_______________________________________________________

_______________________________________________________
Unit 3

Insulation Materials and Systems
Unit 3 Insulation Materials and Systems

Insulation material of many different types may be employed to create a high performance thermal envelope in a building. The previous sections of this manual have considered the process by which heat is transferred in buildings and the calculation of the performance of the different elements in the building envelope. In this unit, the properties of insulation materials are considered in relation to suitability for selection for different applications.

**Section 1** explores the various characteristics of some of the most commonly used insulating materials in the construction industry. It considers the implications of these characteristics on how and where each material might be used within the overall fabric of the building.

**Section 2** examines a variety of insulating systems currently used in building construction including many supported through SEAI grant schemes. The systems are also considered in terms of the principles underpinning their successful implementation. This allows for reflection on the knowledge and skills needed by those tasked with their installation.

At the end of this unit you will be able to:

1. Compare the properties of commonly used thermal insulation materials and relate to the criteria to be considered in determining their suitability for selection in building construction applications
2. List and describe a range of commonly used thermal insulation systems including factors in installation affecting their successful performance
Unit 3 Section 1
Properties of Insulation
Materials
1.1 Introduction

The use of thermal insulation materials in buildings has many advantages. Energy costs can be reduced as heat loss or gain decreases. They can control the internal surface temperatures of building elements leading to more comfortable, consistent and easier to control room temperatures. They can also improve the operational efficiencies of installed systems for heating and cooling in buildings.

Insulation materials used in building construction have various properties and characteristics that affect their suitability for different applications. Selection of the appropriate material is not always simply a matter of the thermal performance of one material over another. Factors such as the location of the material within the structure, exposure to moisture and space available for accommodating the insulation within the fabric need to be considered.

The following section looks at the ways that insulation materials work to reduce the rate of heat transfer. The properties of a variety of materials available for use in buildings are considered. Characteristics such as thermal performance, forms the insulation is available in, physical qualities of the insulation and their main applications are presented for each material.

At the end of this section you will be able to:

- Describe the properties of thermal insulation materials commonly used in building construction
- List and describe the factors that affect insulation material suitability across a variety of applications in building fabric construction
1.2 Properties of Thermal Insulation

How does thermal insulation work?

To understand how insulation works we should firstly recall how heat transfer occurs in buildings, i.e. by conduction, convection and radiation. As conduction is the mechanism by which heat moves through materials, most common insulations work by slowing the conductive heat flow. However, there are a number of properties as well as thermal resistance that may affect the suitability of an insulation product for a particular application.

Thermal Resistance

Thermal insulation is designed to trap dry air or gases in its structure, often resulting in lightweight bulky materials. These cells/pockets of trapped air or gas slow down the conduction process and, as they are separated, they also reduce the transfer of heat by convection (see Figure 3.1)

![Figure 3.1: Illustration of how the structure of an insulation material slows heat transfer](image)

Air has a very low thermal conductivity so an insulating material can benefit from inheriting this. This helps slow down the rate at which heat escapes from an insulated building. Depending on the material, various methods are used to trap this air. Some
materials naturally hold onto air, such as sheep’s wool, whereas other materials like polystyrene require a chemical reaction to take place in order to capture the air or gas in the form of bubbles.

Many insulation products combine materials retarding conductive heat loss with a radiant barrier. This often takes the form of a reflective metal foil integrated to one or both surfaces of the insulation material. The foil has minimal insulating quality or heat resistance in its own right but works by reflecting heat back into the room, similar to Low – E glass (see Figure 3.2)

As previously covered in this manual, the thermal conductivity of a material (K or λ value) is the indication of its ability to conduct heat. When we apply the thickness of a material to its thermal conductivity we can establish its thermal resistance (see Figure 3.3 for a comparison of the thermal resistance of building materials). The sum of the resistances in a fabric build-up combines to give us a total resistance, with the inverse of this value establishing the U-value. So most significantly for energy saving, lower U-value equates to a lower rate of heat loss.

Figure 3.2: illustration of the effect of a radiant barrier incorporated in an insulation material
Different insulating materials have varying capacity to absorb and release moisture or let water vapour pass through them. This characteristic of a material is sometimes referred to in a building context as its ‘breathability’. However, the correct technical term is vapour permeability.

A unit used for measuring vapour resistivity of a material is a μ-value (pronounced mu-value). This is a unit that measures a material’s vapour resistivity relative to the properties of air. When applied to the thickness of material, it indicates its vapour resistance in construction. High μ-value means high resistance to transmission of water vapour, e.g. mineral wool and sheep’s wool insulation have a μ-value of 1 while expanded polystyrene has a μ-value of 40.

**Figure 3.3: Thermal resistance comparison of insulation materials and other common building materials at 100 mm thickness**
This property of an insulation product can be particularly significant when it is installed between or around structural timber members. If moisture enters the building fabric, either from the outside by breach of weatherproofing or from inside in the form of water vapour in the air, it is very important that it does not build up or become trapped. Where insulation materials with a high vapour resistance are installed they may retard the drying out of timber members to the outside by diffusion.

Some insulating materials are selected because they are water proof or very vapour tight. This may be a requirement when insulating underground e.g. under a concrete floor slab or below ground level (see Figure 3.4).

Figure 3.4: External insulation at ground level (Reproduced from S.R. 54:2014 with the permission of NSAI)
**Fire Resistance**

This is another important factor when selecting insulation. Some insulation is non-combustible (e.g. mineral fibre) while others may contribute to the spread of flame. Another danger is that the combustion of some materials will lead to the emission of toxic gas. It is important to check that any material with the potential to be exposed to fire is compliant with relevant European and Irish standards for fire safety in buildings.

There may be instances where an insulation system being used needs to adapted to facilitate fire safety regulations. Examples of this would be detailing at party walls to prevent spread of fire to adjoining building or the accommodation of a flue penetration where there is potential for combustion (see Figure 3.5).

![Figure 3.5: Flue penetration through external insulation (Reproduced from S.R. 54:2014 with the permission of NSAI)](image)

**Mechanical Properties**

The density of an insulation material is not directly related to its thermal performance, i.e. as already stated insulation is often characterised by being bulky and lightweight. However, the mechanical properties of the material such as compressive and tensile strength can affect its suitability for a particular application.

In general, it is important that an insulation material retains its installed dimensions as thermal resistance is directly related to thickness. If a loose fill or quilt type
Insulation material settles resulting in reduced thickness, then thermal performance will be affected. Insulation installed vertically in walls can also suffer performance issues where settlement leads to gaps in the layer at junctions.

There are also specific applications where the compressive/tensile strength of insulation is significant. A common example would be the need to provide an insulated walkway in a loft for access to water tanks and services. External insulation also needs to be resistant to impact to avoid indentation or surface damage.

"Ma'am, I'm afraid the insulation in the walls of your gingerbread house contains dangerously high levels of cholesterol."
1.3 Types of Insulation Materials

While it is established that there are a number of factors to consider when selecting insulation materials, fortunately there are a wide variety available to choose from. The following is an overview of materials commonly used in Ireland which considers thermal performance, forms the material is available in, physical qualities and main applications.

Sheep's Wool

Sheep’s Wool insulation is natural fibre taken from sheep that have not been dipped in chemicals. It is washed thoroughly to remove the lanolin (naturally occurring fatty substance) and often then mixed with a small percentage of polyester to help it retain its shape. Sheep’s wool has the capacity to absorb up to 35% of its own weight in moisture without affecting its thermal performance.

![Figure 3.6: Thermafleece Eco Roll brand sheep’s wool quilt insulation (courtesy of Ecological Building Systems Ltd.)](image)

Availability and Applications

Sheep's wool is generally available in rolls and batts (rectangular sections) 400 mm and 600 mm wide, in thicknesses of 50 mm, 75 mm and 100 mm. Applications include loft insulation, between rafters, raised timber ground floors and in timber frame construction.
Physical Qualities

Sheep’s wool is a semi-rigid, easily cut, non-irritating material. It has the ability to absorb and release moisture, i.e. a hygroscopic material. It may be cut to size with a knife or shears and requires no protective equipment to install. The material is compressible enough to accommodate fluctuations in timber stud/rafter centres while staying in position with a tight fit. The material is treated with an insecticide to deter nesting but been known to be susceptible to rodent infestation.

Fire Resistance

Sheep’s wool will melt in contact with flame but usually extinguishes itself. It does not emit toxic gases on combustion and can be treated with a fire retardant to reduce the risk of spread of fire.

Thermal Performance

Sheep’s wool has a very similar thermal performance to glass/rock wool insulation. Thermal conductivity is 0.039 W/mK.

Mineral Wool Insulation

Mineral wool insulation is available in two types, glass mineral wool and stone mineral wool. Glass mineral wool insulation is made from sand and up to 80% recycled glass. This material is spun into fibres which are layered. Modern versions are manufactured with additives to prevent the irritation of the lungs and skin previously associated with the material. Stabilisers are now added in order to minimise the release of the fine glass dust decreasing the potential for irritation. Manufacturers can substitute up to 50% of the raw material used with recycled glass.
Availability and Applications

Glass/stone mineral wool insulation is available in a variety of forms including:

- **Quilt** - usually in rolls 1200 mm wide and sometimes pre-cut for 400 mm and 600 mm centres. In this form it is used in timber floors, roofs and timber frame construction

- **Batts and semi-rigid slabs** – for placing between timber studs/joists or partial fill of cavity wall

- **Loose fibre** – for blown in loft insulation

Physical Qualities

The insulation has a low vapour resistance with a $\mu$-value of 1. It may be cut to size with a knife or hand saw and requires protective equipment such as gloves and a dust mask to install. Similar to sheep’s wool, it is compressible enough to accommodate fluctuations in timber stud/rafter centres. It is also a water repellent and decay proof material.

Fire Resistance

Glass/mineral fibre is a non-combustible material that will withstand temperatures up to 230 °C.
## Thermal Performance

Thermal conductivity typically ranges between 0.032 and 0.044 W/mK.

## Stone Wool Insulation

Stone wool insulation is manufactured from volcanic rock which is blended with coke and limestone. The crushed stone is heated, melted and spun into fibres and layered. Slag, a waste product from blast furnaces, is now often used in stone wool production.

![Stone wool insulation installed to timber frame construction](image)

**Figure 3.8: Stone wool insulation installed to timber frame construction**

## Availability and Applications

Similar to glass fibre, stone wool is manufactured in quilt or batt form and also in rigid slabs.

- **Quilt** - usually in rolls 1200 mm wide for use in timber floors, roofs and timber frame construction
- **Batts and semi-rigid slabs** – for placing between timber studs/joists or partial fill of cavity wall
- **Loose fibre** – for blown in loft insulation
- **Rigid slabs** – for use in warm/cold roof construction and external wall insulation (EWI)
- **Resin bonded rigid slabs** – for use in floor construction

Rockwool is used for insulating timber walls, timber floors, rafters, lofts and external wall insulation (EWI)

### Physical Qualities

Rockwool has a low $\mu$-value of 0.6, so is vapour open, but is a denser material than glass fibre. Similar to glass fibre, it may be cut to size with a knife or hand saw and requires protective equipment such as gloves and a dust mask to install. Its high compressive strength makes it more suitable than some of the other quilt insulations for certain applications, including external wall insulation.

### Fire Resistance

Rock wool is a non-combustible material that will withstand temperatures up to 850 °C.

### Thermal Performance

Similar to glass fibre, thermal conductivity typically ranges between 0.035 and 0.040 W/mK.

### Cellulose Insulation

Cellulose insulation (see Figure 3.9) is manufactured using recycled newspaper and other waste paper. It is treated with Borax as a fire retardant measure and an anti-fungal agent. This also reduces the risk of insect and vermin infestation.
Available and Applications

Cellulose insulation can be used directly from bags for insulating floors and lofts. It can also be blown in for these applications and, additionally, the insulation of timber frame walls and sloping roof voids.

Physical Qualities

Cellulose is supplied in dry forms (loose fill) and sometimes with the addition of small amounts of water and adhesive for ‘wet spray’ applications. This use of additive reduces settlement and maintains dimensions. It does not cause irritation like glass or rock wool and may be applied without protective clothing. Dry variants can be dusty though and some people may prefer the protection of a dust mask. It is also a hygroscopic material with a low $\mu$-value of 2.

Fire Resistance

The addition of Borax in the manufacturing process gives cellulose insulation a fire rating of Class 1 in the UK, i.e. least distance and lowest spread of flame.
Thermal Performance

Thermal conductivity of cellulose insulation typically ranges between 0.035 and 0.040 W/mK.

Wood fibre Insulation

Wood fibre insulation uses by-products from timber manufacturing processes as a raw material to produce insulation boards. Wood chips are ground into a wood fibre pulp. Insulation boards are produced using either a wet or dry manufacturing process.

In the ‘wet process’, the pulp is mixed with water and paraffin or latex and pumped into a forming tray to create a continuous fibre mat. This is then dried and compressed to reach its final moisture content before being cut to size. Boards are manufactured up to 25 mm thickness using this process but greater thicknesses can be achieved by laminating together multiple plies.

The ‘dry process’ involves spraying the pulp with paraffin, drying and then spraying with a PU resin before being distributed into forming trays. The mat is then cured and hardened. This process is used to manufacture boards in thicknesses up to 240 mm.

Figure 3.10: Gutex brand wood fibre insulation board with tongue and groove installed on pitched roof (photo courtesy of Ecological Building Systems)

Availability and Applications

Wood fibre insulation is available in an array of board thicknesses and sizes depending on application. Boards are available for insulating between, above and
below timber studs, joists and rafters. Thicknesses can range from 18 mm to 240 mm depending on the product type and application.

**Physical Qualities**

Wood fibre insulation is available in a variety of densities and compression strengths that have a multitude of applications in floors, walls and roofs. It can be a rigid or semi-rigid board which is cut to size using hand or power tools usually associated with woodwork. The products are similarly hygroscopic to other forms of timber, with an average $\mu$-value of 5 and, therefore, integrate very well with timber frame construction. It is a renewable/sustainable product which recycles the by-product of timber manufacturing.

**Fire Resistance**

Wood fibre insulation shares a similar fire resistance to other timber products and does not usually employ fire retardant in the manufacturing process. Most boards have a Euroclass fire reaction of E.

**Thermal Performance**

Thermal conductivity of wood fibre insulation typically ranges between 0.038 and 0.044 W/mK.

**Polystyrene Insulation**

Polystyrene insulation is used in building construction is available in two distinct variants; Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS)

EPS is produced when beads of Polystyrene are expanded, and then cooled. Once inside a mould, they are injected with low-pressure steam, which further expands them and fuses them together. EPS comes in two types, the traditional white EPS and the more modern grey EPS. Grey EPS is also called "platinum" or Graphite Enhanced Expanded Polystyrene. Adding graphite to the EPS enhances the thermal properties of the insulation.

XPS insulation begins as a solid polystyrene resin granule. The granules are fed into an extruder and a blowing agent is injected to make the mixture foamable. Its excellent resistance to moisture, imperviousness to rot, mildew and corrosion, make XPS foam an excellent choice in places where you expect constant water or dampness.
**Availability and Applications**

Polystyrene insulation can be used in a wide variety of applications including ground floor, flat roof and external wall insulation (EWI). Because of its high compressive strength and resistance to water absorption, it is a good choice for warm flat roof constructions where there may be foot traffic over. Boards are also available laminated to particle boards or plasterboards (for internal wall insulation).

**Physical Qualities**

Polystyrene board is highly resistant to compression with XPS available in densities ranging from 20 to 40 kg/m³. It is highly resistant to water absorption and therefore very durable in exposed locations. It also has a natural resistance to fungal growth and rot and does not attract nesting insects or vermin. EPS has a $\mu$-value of 60 while XPS has a $\mu$-value of 150 so they are both relatively vapour tight.
Fire Resistance

Polystyrene is a combustible material and will burn rapidly when exposed to flame, with an additional danger of toxic fumes from combustion. Some products are available with the addition of fire retardant but they should be checked rigorously against standards for fire safety.

Thermal Performance

Thermal conductivity of polystyrene insulation typically ranges between 0.035 and 0.0025 W/mK.

Urethane Insulation

Rigid urethane is a term used to describe a number of insulation products incorporating Polyurethane (PUR) and Polyisocyanurate (PIR). PUR insulation can either come as spray foam or a rigid board. It is manufactured by chemical reaction between two components, isocyanate and polyalcohol. For PUR insulation boards, the material is cured to form a panel and a foil coating is applied to both sides.

Figure 3.12: Xtratherm brand Polyurethane (PUR) Insulation panel in partial fill cavity wall (courtesy of Xtratherm Limited)

PIR is formed by the same chemical reaction as PUR but with different ratios between the two components. PIR has one of the best thermal performances of any insulation in common use in the building industry in Ireland today.
Availability and Applications

Urethane is available in a number of board sizes and thicknesses from 12 mm to 200 mm. It is used in many applications including ground floors, partial fill cavity walls, external wall insulation (EWI), flat and pitched roofs. The thinner boards are useful for counteracting localised thermal bridging effects. The boards are manufactured with foil coatings to both faces which can improve the thermal resistance of the insulation by acting as a radiant barrier when placed adjacent to an air space.

Spray foam insulation (PUR) is also available where the components are transported to the site in liquid form. They are mixed as they are blown in a 1:1 ratio by the spraying equipment into the desired locations and begin to cure immediately on contact with air (see Figure 3.13). During the reaction between the two components, a cellular structure is formed which is either ‘open cell’ or ‘closed cell’. A water based system is used to form open cell foam insulation which is considered more ‘breathable’ than the closed cell variant.

Figure 3.13: Spray applied urethane insulation

Physical Qualities

Urethane boards are highly resistant to compression and have a high level of shear strength. They are dimensionally stable and may be accurately cut to size using a handsaw or specialist knives. They are resistant to water absorption and very durable in exposed locations. They are also resistant to fungal growth and
rot and do not attract nesting insects or vermin. PUR and PIR have a $\mu$-value of 60 so they are both relatively vapour tight.

**Fire Resistance**

Urethane foam is a combustible material and will burn rapidly when exposed to flame with high levels of smoke produced in fire. PIR performs significantly better than PUR in fire with reduced combustibility but the products should be checked rigorously against standards for fire safety.

**Thermal Performance**

Thermal conductivity of rigid urethane insulation typically ranges between 0.019 and 0.025 W/mK. Thermal conductivity of sprayed open cell urethane insulation typically ranges between 0.032 and 0.037 W/mK.

**Phenolic**

Phenolic insulation is rigid foam that is produced by mixing solids and phenolic resin with a blowing agent (most commonly pentane). A chemical reaction takes place during the mixing process which creates heat that evaporates the liquid blowing agent resulting in a structure of small bubbles. The material is then cured to form sheets or made into blocks which can be shaped. The sheets have a thin layer applied to both faces (usually foil) and cut to size. Plasterboard is sometimes laminated to one face to create internal wall insulation (IWI) board.

![Image of Xtratherm Safe-R Phenolic insulation board](source: www.xtratherm.com)

**Figure 3.14: Xtratherm Safe-R Phenolic insulation board (source: www.xtratherm.com)**
**Availability and Applications**

Phenolic insulation board is used in ground floors, pitched roofs, partial fill cavity walls, external wall insulation (EWI) and internal wall insulation systems (IWI). The boards are available in a number of sizes, commonly 1.2m x 2.4m, and thicknesses ranging from 20 mm to 125 mm. The thin boards are useful for detailing to counteract thermal bridging effects as they have a relatively high thermal resistance for their thickness.

**Physical Qualities**

The boards are produced in densities ranging from 35 kg/m³ to 200 kg/m³. The higher density versions have good compressive strength which makes them suitable for floor applications. Phenolic has anti-fungal properties and does not attract nesting insects and vermin. The product is dimensionally stable and may be accurately cut to size using a handsaw or specialist knives. The material has a fine closed cell structure which is highly resistant to moisture with a $\mu$-value of 50.

**Fire Resistance**

Phenolic has the best fire resistance of the rigid foam insulation boards available. It is a self-extinguishing, low smoke emission material.

**Thermal Performance**

Thermal conductivity of phenolic insulation is typically 0.020 W/mK in the density range 35 kg/m³ to 60 kg/m³.

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**Aerogel Insulation**

Aerogel is a low density solid derived from a gel (most commonly silica) in which the liquid component has been replaced by a gas. This results in an extremely lightweight material which contains 95 – 97% giving it excellent insulation qualities.

**Availability and Applications**

Aerogel insulation is available in different forms. Aerogel granules can be used as a full cavity fill material in the cavity of glazing units, both glass and polycarbonate. It is available in thin plastic encased strips for applying to the face of timber or metal studs to reduce the repeated thermal bridging effect associated with framed
external elements. It is also available as a blanket material, in rolls, which can be used in pitched roofs, walls, floors and lofts. A product which has Aerogel blanket laminated to a fibrous material is now on the market with thermal conductivity of 0.013 W/mK.

**Physical Qualities**

Silica Aerogel has characteristics which make it an excellent insulator. It is a good convective inhibitor as air cannot circulate through it. It has excellent conductive qualities because of the high percentage of still air.

Aerogel can be cut to size with conventional textile cutting tools such as knives and scissors. The material can be dusty and protective clothing and dust masks should be worn. Aerogel has natural anti-fungal properties. It has high compressive strength for such a lightweight material which makes it suitable for use in floors.

**Fire Resistance**

Aerogel has good fire resistance properties with a 'Class A' rating in the USA and Euroclass C.

**Thermal Performance**

Thermal conductivity of Aerogel insulation typically ranges from 0.013 W/mK to 0.019 W/mK.

A summary of the applications and characteristics of insulation materials is provided in Table 3.1.
Table 3.1: Summary table of insulation materials

<table>
<thead>
<tr>
<th>Insulation Type</th>
<th>Category</th>
<th>Applications</th>
<th>Conductivity W/mK</th>
<th>μ-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep's Wool</td>
<td>Blanket/quilt</td>
<td>Loft, rafters, timber floors, timber frame</td>
<td>0.035 - 0.044</td>
<td>1</td>
</tr>
<tr>
<td>Glass Wool</td>
<td>Blanket/quilt or loose blown-in</td>
<td>Loft, rafters, timber floors, timber frame</td>
<td>0.032 - 0.044</td>
<td>1</td>
</tr>
<tr>
<td>Stone Wool</td>
<td>Blanket/quilt or loose blown-in</td>
<td>Loft, rafters, timber floors, timber frame, EWI</td>
<td>0.035 - 0.044</td>
<td>1</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Loose blown-in</td>
<td>Loft, rafters, timber frame</td>
<td>0.035 - 0.040</td>
<td>2</td>
</tr>
<tr>
<td>Wood Fibre</td>
<td>Rigid board</td>
<td>Loft, rafters, timber floors, timber frame, EWI, IWI</td>
<td>0.038 - 0.044</td>
<td>5</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>Rigid board</td>
<td>Concrete floor, flat roof, EWI</td>
<td>0.025 – 0.035</td>
<td>60 - 150</td>
</tr>
<tr>
<td>Urethane</td>
<td>Rigid board or loose blown-in</td>
<td>Concrete floor, rafters, flat roof, EWI, IWI</td>
<td>0.019 - 0.025 0.032 - 0.038</td>
<td>60</td>
</tr>
<tr>
<td>Phenolic</td>
<td>Rigid board</td>
<td>Concrete floor, rafters, flat roof, EWI, IWI</td>
<td>0.020</td>
<td>50</td>
</tr>
<tr>
<td>Aerogel</td>
<td>Blanket, strip or granules</td>
<td>Loft, walls, rafters, thermal bridging, glazing</td>
<td>0.013 - 0.019</td>
<td>5</td>
</tr>
</tbody>
</table>
Summary

- Most insulation materials work by trapping air or gas in their structure to provide good conductive resistance to heat flow.
- A number of factors other than thermal resistance need to be taken into account when selecting the appropriate material for an application in a building. They include vapour/moisture resistance, fire resistance and the mechanical properties of the material.
- Insulation materials such as sheep's wool, glass fibre and rock wool have good vapour diffusion qualities and may be used in applications where they are installed between timber members. They accommodate drying out in the event of moisture build up in the fabric.
- Materials such as glass fibre, rock wool and cellulose are available in loose fill forms which may be blown in for insulating lofts and walls. They can be useful when access is limited to fill voids.
- Insulation materials such as polystyrene, rigid urethane and phenolic boards are good in compression and are suitable for concrete floor applications. They are also vapour tight and highly resistant to water making them durable in exposed or below ground locations.
- Urethane insulation is also available in a spray form in open cell and closed cell variants.
- Aerogel insulation offers the highest thermal resistance of any mainstream insulation product on the market. It is particularly useful for applications that require high performance for low thickness.
M2.U3.S1 Progress Check

1. List and describe three characteristics of an insulation material that should be considered in their selection for use in a building

   1) _______________________________________________________
   2) _______________________________________________________
   3) _______________________________________________________

2. Describe a method for improving the dimensional integrity and reducing settlement in cellulose insulation

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

3. List three insulation materials that would be suitable for insulating a concrete slab-on-ground floor

   1) _______________________________________________________
   2) _______________________________________________________
   3) _______________________________________________________

4. Describe the insulating property a foil facing provides to insulation material

   __________________________________________________________
   __________________________________________________________

5. List four insulation materials which could be considered for insulating a pitched roof at ceiling level to current building standards.

   1) _______________________________________________________
   2) _______________________________________________________
   3) _______________________________________________________
   4) _______________________________________________________
6. Describe the ‘wet process’ method of manufacturing wood fibre insulation products

7. Name four insulation materials that are commonly used in external wall insulation (EWI) systems
   1) ________________________________
   2) ________________________________
   3) ________________________________
   4) ________________________________
Unit 3 Section 2
Common Insulation Systems
2.1 Introduction

The amendments to the building regulations since 2002 emphasising energy performance have had a profound influence on the design and construction of building fabric. Many of the changes to the building standards are rooted in the principles of continuity of insulation and air tight envelopes. Comprehensive detailing of fabric elements to account for insulation levels, thermal bridging and air tightness is necessary. This has been reinforced by the introduction of the Building Energy Rating (BER) system and the testing regime for building air permeability standards.

Sustainable Energy Authority of Ireland (SEAI) schemes for upgrading the energy efficiency of buildings have also boosted the market for products and systems which improve fabric performance. The NSAI provides certification schemes for many of these products and their installers in an effort to regulate quality.

Manufacturers of related materials and systems have responded to demand with the development of products that aim to meet the higher specification now required for achieving building fabric performance levels. This section considers existing and emerging insulation systems by building element. Reflection is also provided on the requisite skills and knowledge needed to successfully implement these systems.

At the end of this section you will be able to:

1. List and describe common insulation systems that may be deployed to enhance energy performance of floors, walls, roofs and windows
2. Relate the principles underpinning successful performance of these systems with the knowledge and competence levels of construction workers required for their implementation
2.2 Insulation of External Walls

In the last 100 years, external wall construction in Ireland has been dominated by masonry single leaf and, more recently, twin leaf (cavity wall) construction. From the beginning of the last century to the early 1970's, single leaf construction was to the fore. Initially, in urban areas, brick was the most common walling material while natural stone was used predominantly in rural one-off housing projects. These materials were largely replaced in later years by the introduction of concrete and the concrete block. This move to concrete materials was facilitated by the Irish government's Cement Act of 1933, which led to a full scale production of cement from 1938. It resulted in a widespread use of mass concrete for walling up to the 1950's, both in urban housing schemes and in loose shuttered concrete walling (not mechanically vibrated) construction in rural areas.

Internal Wall Insulation (IWI)

Un-insulated solid concrete and hollow block walls rendered internally and externally dominated the period between 1950 and the late 1970's. Hollow block single leaf construction has been most commonly used in the densely populated Leinster region for the past 40-50 years. Internal wall insulation or *Dry lining* of hollow block walls was introduced in the late 1970's and has continued to be used as a retrofit measure for single leaf masonry walling.

The IWI system initially in widespread use comprised an insulation layer of glass or wool fibre fitted between timber battens which were fixed at centres to the inner face of the wall. A vapour barrier was placed over the battens and insulation, often a polythene sheet. Gypsum plasterboard was fixed over and finished with either taped joints or with Gypsum wet applied skim coat plaster (see Figure 3.16).

This system often incurred poor performance, particularly significant issues with surface and interstitial condensation. The battens fixed at centres formed repeated thermal bridging and usually there was no insulation returned at the reveals of openings. Continuity of insulation at junctions with adjacent walls, ceilings and floors were also a concern. The polythene used as a vapour barrier was often poorly fitted and, allowing for vapour ingress into the fabric through gaps to condense, resulting in a sweating effect.
Figure 3.16: Typical dry-lined hollow block external wall construction (Source: SEAI - Passive House Retrofit Guidelines)

In recent times, dry lining has also been applied as an energy efficiency upgrade to various types of solid single leaf walling. Composite boards of rigid slab insulation and gypsum plasterboard have become available for internal insulation, generally incorporating an integrated vapour control layer (see Figure 3.17).

Figure 3.17: Thermal laminated board fixed to internal face of wall (Reproduced from S.R. 54:2014 with the permission of NSAI)
It is important that the vapour control layer be well sealed at wall, floor, ceiling, door and window junctions, around light switches and at all other breaks in the insulation as interstitial condensation (moisture build-up within the fabric) is a real risk when insulating internally. Therefore, it may be argued that this system has a limited suitability in retrofit applications. However, this has not affected the widespread usage and these types of systems have been eligible for grant aid under various energy efficiency upgrade schemes.

As with the majority of energy efficient applications, attention to detail is crucial to ensure correct performance and avoid compromise. Some thermal lamintated boards for example, are being supplied by builder’s merchants with metal fixings to mechanically attach the boards to the walling. This practice results in multiple thermal bridging pathways through the wall insulation.

Guidance in current building regulations and the recently published Retrofit Code of Practice (NSAI, S. R. 54) emphasise good practice in installation of IWI. The use of additional layers of insulation and detailing at door and window reveals is encouraged to counteract thermal bridging effects. Methods of maintaining integrity of vapour control layers are also outlined, such as provision of service voids (see Figure 3.18).

![Figure 3.18: IWI with service void formed by timber batten](Reproduced from S.R. 54:2014 with the permission of NSAI)
 Typically, these systems are installed by plasterers or carpenters for both new build and in retrofit applications. A fundamental understanding of the principles of thermal bridging, air tight construction, material suitability and interstitial condensation is required to ensure successful results.

**External Wall Insulation (EWI)**

External wall insulation (EWI) has become widely regarded as best practice for the retrofitting of masonry walls for energy performance. External wall insulation has a number of clear advantages over internal systems as a continuous insulation envelope can be created. This enables the elimination of thermal bridging and significant improvement to the structural air tightness of the building.

By virtue of the fact that the insulation is fitted to the outside of the building, any potential interstitial condensation will be isolated externally to incur little or no adverse effect. Also in its favour, this system of insulation does not impinge on the floor space of a building.

External insulation involves fixing insulation materials such as mineral wool, expanded polystyrene or Polyisocyanurate (PIR) slabs to the outer surface of the wall. This insulation is finished externally with an acrylic or cement-based render to provide weather resistance. A steel or fibreglass mesh (scrim) is embedded in the render to provide strength and impact resistance (see Figure 3.19).

*Figure 3.19: Typical External Wall Insulation system using wet render (Reproduced from S.R. 54:2014 with the permission of NSAI)*
A thinner layer of insulation is fitted around the window and door reveals to minimise thermal bridging. Existing concrete window sills are cut back and replaced by proprietary sill covers with integrated insulation layers to reduce thermal bridging.

Correct detailing at flashings, plinths and abutments is extremely important to optimise performance. Attention is also needed to fire resistance factors and maintaining function of drains, sewers, gutters and waste pipes. Most significantly, as the system is so effective in reducing air infiltration, adequate controlled ventilation requirements need to be maintained or reinstated according to the needs of the dwelling.

ESB Networks and Bord Gais have also published specific guidance for dealing with service cables, pipes and meter boxes which are affected by the external insulation installation.

For external insulation, the SEAI insist on the use of NSAI Agrément certified products and only list approved contractors that have registered under the NSAI Agrément registered installer scheme as eligible for grant support. NSAI Agrément offer registration to installers of Blown Loft Insulation (see xx later), Full Fill Cavity Wall Insulation (see xx later) and External Insulation. Installers are often from a plastering or bricklaying background (wet trades). Similarly to internal dry-lining, an understanding of air tightness/ventilation and thermal bridging is essential to successful installation.

**Cavity wall systems**

Cavity wall construction became more widespread in Ireland in the 1950’s with the fitting of insulation in the cavity appearing in the late 1970’s. This system of wall construction has been regarded as best practice since. The twin leaf construction initially became popular as it was extremely effective in preventing moisture ingress through external walls relative to single leaf which relies mainly on the external render for moisture protection. This was recognised as a major factor in its choice to combat the high levels of driving rain associated with the Irish climate, particularly in the exposed coastal areas of the country.

The advantages of including insulation in the wall cavity to reduce heating requirement seems to have been largely influenced by the upward shift in fuel costs stemming from the oil crisis in the early 1970’s. Regulations specific to energy efficiency in dwellings were introduced in 1976 and initially required 40mm of insulation in the cavity with 50mm becoming the standard after 1991.
The most commonly adopted cavity wall construction became a 100mm external masonry leaf with a 105mm air cavity partially filled with insulation. An air cavity was maintained on the cold side with a 100mm inner masonry leaf provided. Plastic or metal cavity ties were fitted at regular intervals to provide structural stability and to retain the insulation material against the inner leaf. The insulation is fitted by the block layer as the walling is constructed in courses (Figure 3.20).

![Figure 3.20: Typical Cavity Wall Detail (Source: SEAI, Passive House Retrofit Guidelines)](image)

With amendments to TGD L in 2002, 2007 and 2011, the maximum elemental U-value for walls has decreased to 0.21W/m²K. This has pushed the boundaries of this construction as a cavity of up to 150mm is now required to accommodate high performance insulation boards while still retaining a minimum air cavity thickness of 40mm. Proprietary systems for cavity closing around openings have also been introduced to the market to facilitate the achievement of thermal bridging standards set by the Building Regulations.

These performance standards necessitate particular attention to detail in cavity wall construction in order to achieve continuity in the insulation layer. At installation, the insulation material is fitted tight at joints, with particular attention required around openings and junctions. Insulation must also be tight to the inner leaf in order to avoid a phenomenon known as “thermal looping”, where air circulation occurs between the air cavity and gaps on the warm side of the insulation.
Existing cavity walling also lends itself to energy retrofit through pumped full-fill cavity insulation technology. This system involves drilling a series of holes in the outer leaf of the external wall. This is to accommodate the nozzle of a pump through which insulation is fed into the cavity to fill any voids (see Figure 3.21). NSAI currently approve bonded bead type polystyrene insulation but there are also polyurethane foam alternatives on the market.

![Figure 3.21: Pumped Full Fill Cavity Wall Insulation](image)

Suitability of a cavity wall needs to be determined in advance before using this system to investigate any issues with water ingress or damage in the cavity. At installation, the flow rates of the pumped insulation and centres at which holes are drilled in the external leaf requires careful attention. This is to ensure that the cavity is completely filled. Maintaining designed ventilation is also essential.

This system has certain limitations as the improvement to the insulation layer in the cavity is bound by the existing cavity construction. Existing thermal bridging in the wall at openings and junctions created by closing of the cavity will therefore remain.

### Insulation systems for timber frame construction

Timber frame construction has experienced a rapid growth in Ireland over the past 20 years. In the early 1990’s timber frame accounted for only 5% of all construction. However, by 2006 this share had increased to 30%, predominantly due to change in
consumer attitude. Originally, masonry construction was perceived as essential to withstanding the harsh weather conditions in Ireland. One of the main selling points for timber frame was the potential savings on heating bills as the system accommodated high thicknesses of insulation material relative to other constructions.

During the construction boom in Ireland from the mid 1990’s to 2008 this system of construction became more popular with developers, mainly due to the speed of completion possible. The main building elements are factory manufactured (walls, intermediate floors, roof trusses) and can be transported to site for rapid assembly. There is also a time saving in the required drying out period relative to masonry construction.

Typically in Ireland, external wall panels comprise of a structural timber frame inner leaf with a masonry external cladding layer of brick or rendered concrete block forming a cavity to prevent water ingress (see Figure 3.22). The inner load bearing layer is constructed from a softwood stud frame which is stiffened with a sheeting panel (usually OSB or Plywood) on the cold side. The void between the timber studs is filled with thermal insulation and the frame is fitted internally with a vapour barrier and gypsum plasterboard over. A weather proof breather membrane is also applied on the outside of the plywood/OSB sheeting.

![Figure 3.22: Typical traditional timber frame external wall construction (Source: SEAI, Passive House Retrofit Guidelines)](image-url)
Questions began to arise in recent years as to the actual energy performance of timber frame buildings. When air permeability tests were introduced with the 2008 Building Regulations, results for timber frame dwellings were generally inferior. The typical construction details used did not consider air tight seals at junctions and openings. Also, little regard was paid to the potential impacts of thermal bridging for both repeated as part of the main structure and those occurring around openings/penetrations in the insulation envelope.

In the last four to five years particularly, the need for compliance with revised building regulations has meant that the approaches being taken in timber frame construction have evolved. This has led to industry embracing the principles of air tightness and insulation envelope continuity. Some companies have adopted materials and systems from continental Europe, particularly Scandinavia, Germany and Austria, which emphasise building energy performance.

The majority of assembly and installation work is carried out by carpenters. Using modern timber frame systems, this increasingly involves detailing for air tightness and thermal bridging. Figure 3.33 illustrates the layering of insulation with timber framing fitted perpendicularly to counteract the effects of thermal bridging. Service cavities are also incorporated on the warm side of the insulation and inside the vapour control/air tight layer. This allows for the installation of services without compromising air tightness and insulation continuity.

Figure 3.33: High energy performance timber frame external wall construction (source: SEAI, Passive House Retrofit Guidelines)
2.3 Insulation of Ground Floors

The vast majority of ground floor construction in Ireland can be divided into two categories; solid concrete slab-on-ground and suspended floors, available in both concrete and timber variants.

**Solid concrete slab-on-ground**

Solid concrete slab-on-ground has become the most common practice in Ireland since the 1980’s. The topsoil (vegetation layer) is removed and a layer of hardcore fill is provided and blinded with sand before a Damp Proof Membrane (DPM, sometimes incorporating a Radon barrier) is applied. TGD L 2002 defined a minimum elemental U-value and also the need for perimeter insulation “Care should be taken to control the risk of thermal bridging at the edges of floors”. All slab-on-ground floors should be provided with edge insulation to the vertical edge of the slab at all external and internal walls.

The continuity of the insulation layer and safeguarding against thermal bridging is paramount in energy efficient construction. In Ireland, it is common for the insulation layers to be fitted and concrete placed by the general operatives on site. In larger construction firms, operatives may become more specialised as dedicated concrete workers and may also be responsible for steel reinforcement. These workers are also often tasked with the installation of insulation in floors in new build and retrofit applications (see Figure 3.34)

Figure 3.34: Concrete slab-on-ground floor, retrofitted with insulation over slab and connected to internal wall insulation (Reproduced from S.R. 54:2014 with the permission of NSAI)
Guidelines for insulating concrete floors emphasise the need for continuity of the insulation layer, provision of perimeter insulation and, vitally, the relationship with the insulation layer of external walls adjacent to the floor. An understanding of thermal bridging potential and the concept of a continuous building thermal envelope is essential to success.

**Suspended Floors**

Suspended concrete ground floors are usually insulated above the reinforced slab. This method of insulating below a screed has also been adopted as a retrofit measure for slab-on-ground floors (see Figure 3.34 previously).

The raised/suspended timber ground floor is rarely used in new construction in Ireland since the late 1970's. This system comprised of the construction of dwarf or sleeper walls built upon concrete subfloors or foundations with a timber wall plate bedded in mortar or mechanically fixed on top. The sleeper walls were constructed at centres usually between 1.5 – 1.8m. This allowed for a relatively small sectioned timber joist, often 115mm x 38mm, fixed to the wall plate and floored with tongue and grooved floorboards.

This floor would then be ventilated from below with vents in the external walling providing through ventilation from front to rear of the building. The heat loss through the fabric and due to air infiltration is very significant with this system. Energy retrofit solutions vary between sealing the flooring at all joints to complete removal of flooring with insulation material fitted between joists and air tight membranes applied above with connection to the perimeter walling (see Figure 3.35).
2.4 Insulation of Roof Constructions

Roof constructions in Ireland generally fall into two categories:

1. Pitched roof – either double pitch roof (sometimes referred to as an A roof due to its inverted V shape) or mono-pitch with a single sloping side.
2. Flat roof - which is often but not always completely horizontal. The roof may be up to 10% off the horizontal to create a fall to divert rainwater. This can also be achieved with horizontal flat roofs by the addition of a firring piece (a tapered timber member) to create a fall to the roof deck.

When installing insulation layers for both these categories, they may be constructed as either a warm or cold roof. With a cold roof construction the insulation is located on the inside (warm side) of the roof structure and vice versa with a warm roof.

**Pitched roof with insulation at ceiling level**

Tiled or slated pitched roofs with a ventilated roof space require insulation and vapour control at ceiling level. Traditionally, quilt insulation was fitted between the ceiling joists with no regard to the recurring thermal bridging through the joist timbers, i.e.
the timber joists have a lower thermal resistance than the insulation material between them leading to heat loss at a higher rate.

As the thickness of insulation layer required has increased, in line with revised U-value guidance in Building Regulations, a second layer of quilt is now often fitted perpendicularly over the first (see Figure 3.36). Alternatively, a composite board of insulation backed plasterboard can be fitted to the underside of the ceiling joist. Both of these options are based on the principles of continuity of the insulation layer and the minimising of thermal bridging effects.

![Figure 3.36: Roof insulated at ceiling level with two layers of quilt insulation including provision for eaves ventilation (Reproduced from S.R. 54:2014 with the permission of NSAI)](image)

Through ventilation from eaves to eaves of the roof space should be preserved, therefore, particular care to ensure the maintenance of air pathways is required when insulating up to the eaves. A vapour control layer (VCL), either fitted below the ceiling joist or integrated into a composite board, is essential to limit the transfer of water vapour to the roof space with particular care required to seal any penetration of services etc. through the ceiling layer. Remember, laws of thermodynamics and the fact that warm air rises as it is less dense mean that the hot, moisture laden air will tend to make its way out of the building at the roof level.

In the past number of years, vapour barriers such as polythene and foil backed plasterboards were widely used for this application. However, scant attention was generally given to the continuity of the layer, particularly in the case of the foil backed...
plasterboard where breaks existed at all joints. The concept of controlled passage of moisture through the building fabric had also not been embraced at this time. Engineered vapour control membranes have become available which provide an air tight layer while allowing for vapour diffusion (often referred to as breathability) and avoiding the “sweating” effect sometimes associated with polythene.

Vapour permeability of the insulation material itself is now acknowledged as being significant in building fabric design. Where controlled passage of vapour is accommodated by the VCL, it is important that the insulation does not trap or hold vapour resulting in interstitial condensation.

A number of other factors require attention when insulating ventilated roof spaces (some of which are illustrated in Figure 3.37), these are such as:

1. The first layer of insulation fitted between the joists should be no more than 25 mm above or below the top of the joist. This is to avoid creating a thermal bypass where through ventilation passes between the two layers of insulation.

2. Water tanks and associated pipework should be protected against the risk of freezing. Any pipework located on the cold side of the insulation should be adequately insulated. Water tanks positioned directly over the ceiling joists should be insulated on top and all sides and raised tanks should be insulated independently.

3. Electrical safety needs be carefully considered. Overheating of cables or recessed light fittings should be avoided at installation stage. Cables should be located on the cold side of the insulation if at all possible and adequate provision made for any that cannot.

4. Access to tanks and services in the attic space should be provided for with walkways that maintain insulation levels but are suitably load bearing for purpose.

5. The attic access hatch itself is often ignored in relation to insulation level and, even more significantly, air tightness. Solutions may need to be designed and installed to ensure air tight and insulation envelope continuity while accommodating ladder/roof stair systems.
The retrofit insulation of ventilated roof spaces is generally carried out by companies employing operatives who may have received limited training or instruction. A perception exists that this is a task that requires relatively unskilled labour. The significant number of factors to be accounted for in the installation process surely challenges this notion.

**Insulation at rafter level**

Tiled or slated pitched roofs require insulation at rafter level in the case of occupied or unventilated roof spaces. This can be achieved by either insulating between and below the rafters (cold roof, see Figure 3.38) or between and above (warm roof). In the past, the insulation layer was fitted between the rafters only, which did not account for the thermal bridging effect as described earlier for insulation at ceiling level.

For both constructions, vapour control layers are fitted to the warm side of the insulation and the principle of continuity of insulation and minimising of thermal bridging applies. TGD L 2011 states the importance of locating the more vapour permeable insulation material to the cold side for this construction, to encourage dissipation of water vapour to the outside.
Insulation of flat roof construction

Flat roof construction may be divided into cold deck and warm deck systems. Timber flat roofs in Ireland have traditionally been constructed using the cold deck method with the insulation material fitted between the joists. In the past, this system has suffered from major problems with surface and interstitial condensation due to poor insulation levels, thermal bridging at junctions and inadequate vapour control measures.

The most recent Building Regulations for dwellings suggests the use of an extra insulation layer with a connection to the wall insulation to counter thermal bridging. The use of a VCL and the provision of cross ventilation in a void above the insulation envelope are also indicated (see Figure 3.39). The same principle of vapour diffusion through the fabric as mentioned for pitched roof construction also applies here.
Warm deck flat roof systems are usually used under two categories. One system places the insulation above a concrete slab/timber/metal roof with the waterproof membrane over (see Figure 3.40). The other system is for use with concrete slab roofs with the insulation above the waterproof layer finished with a paving slab or ballast material to accommodate foot traffic onto the roof. The first system requires particular care at installation with regard to prevention of condensation.
### 2.5 Windows & Doors

Single glazed timber or steel frame windows and doors were used predominantly in Ireland up to the 1980’s before the introduction of double glazing and aluminium and PVC frames. A period of widespread window replacement followed as building owners attempted to reduce energy costs. These new window types became very popular as a result of their improved glazing performance and integrated draught seals.

Aluminium framed windows and doors, however, suffered from significant condensation issues as a thermal break was not initially built into their construction. Improvements in glazing technology have followed with the introduction of gas filled cavities (Argon, Krypton) and low emissions metal oxide coatings which reflect heat back into the room (Low - E glass).

In more recent times, the specification of windows and doors has been dramatically affected by the move toward highly energy efficient buildings. This is not just in terms of the materials and assembly used, but also at junctions in the building fabric to provide insulation and air tight envelope continuity. Figure 3.41 illustrates a type of glazing and frame construction used to achieve Passive House standard. Note the use of a PU foam insulation to create a thermal break in the frame and plastic cavity closers to reduce heat loss by conduction.

![Figure 3.41: Section through triple-glazed window of Passive House Standard](image)

- Plastic cavity spacers
- PU foam as thermal break

Figure 3.41: Section through triple-glazed window of Passive House Standard
There is significant scope for energy retrofit solutions to improve the performance of existing windows and doors. Outside of the relatively expensive window replacement option, glazing units can be replaced with higher performing alternatives. Secondary glazing systems may also be installed to the inside of the original window, particularly where there are heritage considerations for maintaining the aesthetics of the building facade (see figure 3.42). Other simple measures such as the fitting of blinds, shutters and curtains can also significantly improve thermal performance.

The air tightness of existing window and door elements can also be improved dramatically by implementing a number of relatively inexpensive measures. These include repair or replacement of draught seals, ensuring that glazing gaskets are continuous and in good order, and the sealing externally and internally of junctions between the window/door frames and building fabric.

Figure 3.4: Examples of side hung and sliding secondary glazing (Reproduced from S.R. 54:2014 with the permission of NSAI)
Summary

- The energy performance of external walls may be optimised by a variety of systems for internal wall insulation (IWI), external wall insulation (EWI) and cavity wall insulation. Systems should be installed to mitigate the potential of water ingress and vapour build up in the fabric due to interstitial condensation.

- Insulation of ground floors should consider the risk of thermal bridging at junctions with walls by providing for a perimeter insulation layer. Raised timber ground floors should also address the significant potential for air infiltration as well as thermal insulation performance.

- Roof constructions may be insulated as warm roof or cold roof variants. Insulation and vapour control at roof level is particularly important as moisture-laden warm air rises and exits predominantly at the uppermost points in a building. Therefore, particular care must be taken to ensure that ventilation pathways are maintained in insulated roof structures as there are additional risks of moisture build-up from leaks in the weatherproofing.

- High performance window and door units with improved U-values over traditional options are now available in the market. Double and triple glazed units employing gas filled cavities and Low-E glass are common. Retrofit options include replacement units, replacement glazing, secondary glazing and use of blinds/shutters/curtains to improve thermal performance. Draught proofing of opening parts and sealing of junctions between units and reveals can significantly reduce heat loss caused by air infiltration.
1. Describe how an external wall insulation (EWI) system may counteract thermal bridging effects at doors and window openings.

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

2. List three precautions that should be taken with the installation of an internal wall insulation system (IWI) to reduce the risk of thermal bridging and interstitial condensation.

1) ______________________________________________________________
2) ______________________________________________________________
3) ______________________________________________________________

3. Describe a method of accommodating services to prevent compromise of the vapour control layer (VCL) in a timber frame wall.

____________________________________________________________________
____________________________________________________________________

4. Name and describe three factors which may affect the thermal performance of a concrete slab-on-ground floor.

1) ______________________________________________________________
2) ______________________________________________________________
3) ______________________________________________________________
5. What factor particularly affects the energy performance of raised timber ground floors?

________________________________________________________________________________

________________________________________________________________________________

6. List and describe the four factors which should be considered when insulating a pitched roof at ceiling level to current building standards.

1) ______________________________________________________________________

___________________________________________________________________________

2) ______________________________________________________________________

___________________________________________________________________________

3) ______________________________________________________________________

___________________________________________________________________________

4) ______________________________________________________________________

___________________________________________________________________________

7. List four possible retrofit measures for improving the energy performance of door and window units.

1) ______________________________________________________________________

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2) ______________________________________________________________________

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3) ______________________________________________________________________

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4) ______________________________________________________________________

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References


